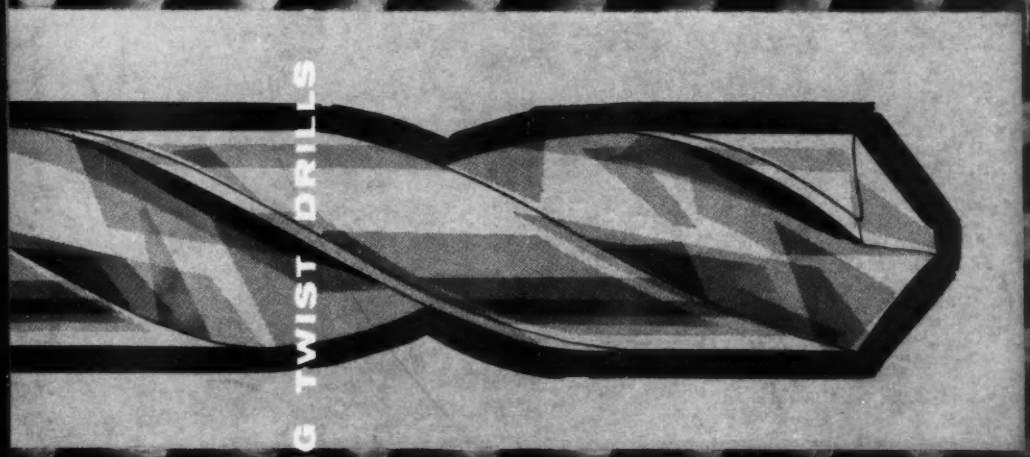
The

ENGINEERS' DIGEST

A World Review of

DESIGN & PRODUCTION · RESEARCH & DEVELOPMENT

VOL. XXII No. 6 JUNE, 1961



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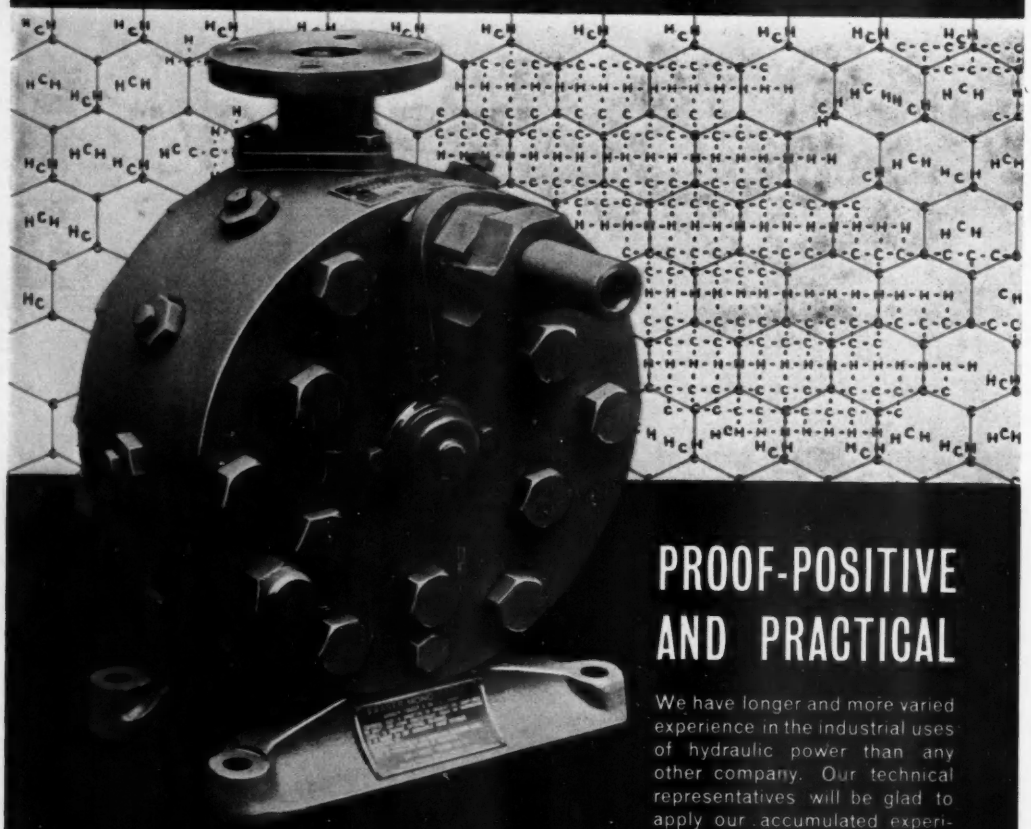

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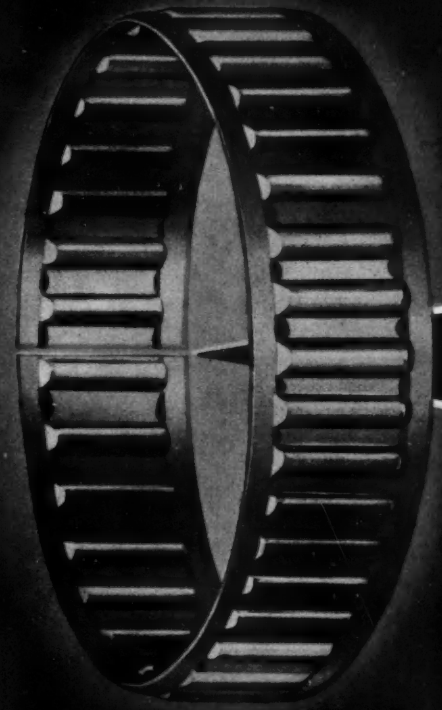

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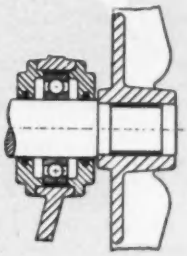

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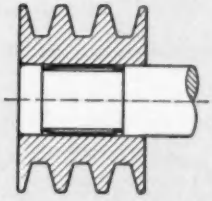

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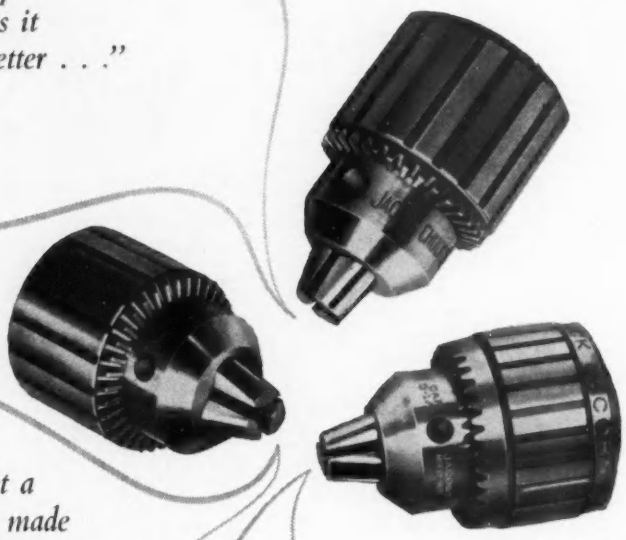

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The ENGINEERS' DIGEST

A World Review of DESIGN & PRODUCTION · RESEARCH & DEVELOPMENT

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The MINIDIGEST

The latest application of remote-control devices without connecting wires is in an **ultrasonically controlled slide-projector** introduced by the Bell & Howell Company, of Chicago, Ill. Designated the "Tele-Sonic Wireless Remote Slide-Projector", this equipment, which can be operated by the remote-control device at distances of more than 40 ft, utilizes an ultrasonic receiving unit in front of the projector to pick up high-frequency sound waves from the remote-control unit, which has no wires or batteries and which contains two pushbutton-operated miniature ultrasonic transmitters, one operating at 36,500 cps for focusing, and the other at 40,000 cps for changing or advancing the slides.

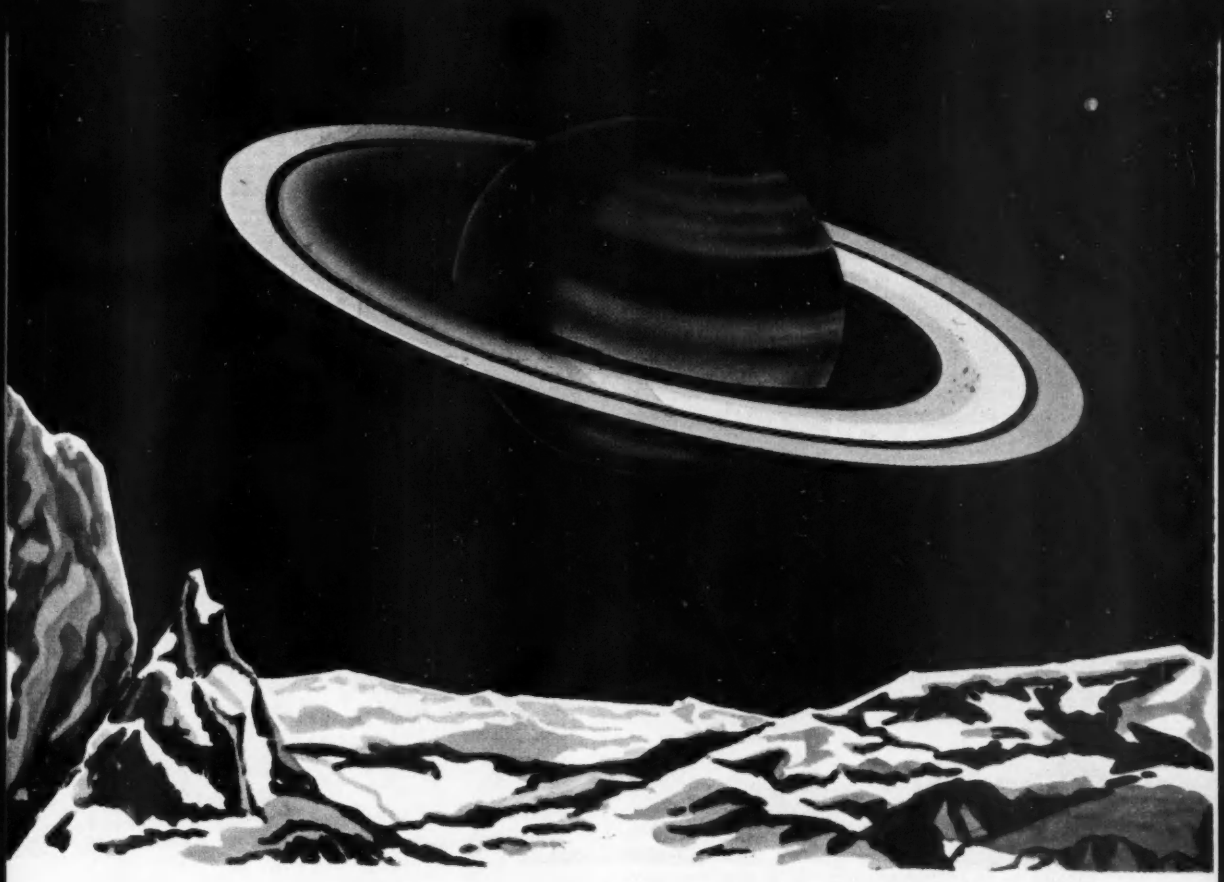
* * *

Since very-high-speed continuous casting can lead to defects in steel, it is necessary to use complex multi-strand casting machines for bulk-steel manufacture. As an alternative, a far more convenient **method of continuous casting** has been evolved in England by the Continuous Casting Company Ltd., in conjunction with the British Iron and Steel Research Association. This method, known as the "Weybridge" process, enables casting speed to be kept at its optimum value and permits the production of billet or bloom sections at rates comparable with those obtained with multi-strand plant, but without the additional operating costs normally associated with such plant. The new process is based on the use of a multiple mould with a cross-section such that the resulting casting comprises several billet or bloom sections, interconnected at their corners and subsequently separated to form a number of individual castings.

* * *

Developed by Epoxy Products, Inc., of Irvington, N.J., a new **epoxy-silver solder** is claimed to furnish a very strong conductive bond with most materials and to be superior in this respect to most metallic solders. At the same time, its resistivity is stated to be between 0·1 and 0·0001 ohm-cm, i.e., comparable with that of metals, and it is suitable for use with heat-sensitive components at comparatively low temperatures. Also, any risk of contaminating sensitive electronic components is eliminated, as it does not contain flux or residue. The solder is available in two forms, i.e., as a single-component paste which heat-cures at about

Balfour products include...



The Planet with the Rings

Saturn is the showpiece of our Solar System.

Revolving ten times further away from the sun than the earth, it is also immensely larger ... 763 earths rolled into one would only just make up Saturn's enormous bulk.

We see the planet and its ring system from a moon called Rhea. Although these rings look solid they are, in reality, made up from myriads of tiny particles most not larger than a golf ball.

Even remote Saturn will one day be visited and in this triumph of technology over nature our Twist Drills, Reamers, Cutters and Engineers' Tools of all kinds will make an essential contribution. Balfours have always produced Tools and Steel for the World: soon it will be for the Worlds.

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The MINIDIGEST

257°F, and as a two-component paste curing at room temperature. When the bond hardens, it can be plated by conventional techniques and can itself be soldered, if desired.

* * *

Details of recent experiments concerned with **producing titanium castings in expendable graphite moulds** are given in the *Report of the Japan Government Industrial Research Institute, Nagoya*, for January 1961. In these experiments, a 99·75% pure titanium containing traces of silicon, carbon, nitrogen, chlorine, and oxygen was cast in graphite moulds of various compositions, optimum results being achieved with moulds containing 65% of graphite powder, 10% of a rapid-drying oil, and 25% of pitch. It is stated that, to ensure consistent quality of the castings, the moulds must first be baked for 1 hr in a vacuum at a temperature of 1000°C and then for 2 hr in air at a temperature of 1100°C.

* * *

According to a note in *Materials in Design Engineering* for May 1961, recent research indicates that **graphite coated with titanium nitride** is showing promise **as a heat-resistant material** for use in missiles and rockets. Thus, tests have shown that graphite, to which a coating of titanium nitride is applied by gas-plating, can withstand a temperature of 3600°F for 1 min in a Mach-2 airstream, whereas uncoated graphite is severely damaged after 20 sec and is destroyed after 1 min in this hot airstream.

* * *

As reported briefly in *Machine Design* for March 2, 1961, a new **sintered-bushing bearing with hydrodynamic-film lubrication** has been developed in the U.S.A. by the Congress Drives Division of the Tann Corporation. The problem of sustaining a low-friction hydrodynamic film within a sintered bearing has been solved by the fact that sintered bronze tends to cold-flow and compact under load, the run-in operation on the bearing producing an oil-impervious surface on the section of the bushing under load, while the rest of the sintered bushing remains porous, permitting a hydrodynamic oil film to be established. The bearing developed is of the pillow-block type and is designed to handle loads in the 50-psi range at speeds of 1750 rpm or higher.

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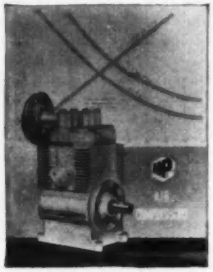

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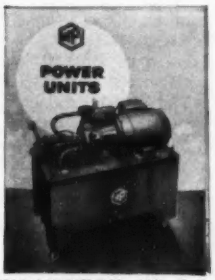

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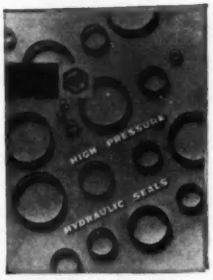

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BUSINESS NOTES

Dewrance & Co. Ltd. announce the formation of the **Dewrance Metals Division,** which will consist of the foundry at Hillington and the Special Alloys Division in London. The new division will have its own board of management and will be responsible for the production and sales of high-quality non-ferrous castings, nickel castings, stainless-steel castings, and hard-facing and high-temperature brazing alloys.

* * *

It is announced by **Charles Colston Ltd.** that they have moved to a new address at Wellington Road, High Wycombe, Bucks. (Tel: High Wycombe 4321).

* * *

An agreement has been concluded between **Lee, Howl & Co. Ltd.,** of Tipton, Staffs. and the **Webster Electric Co.,** of Racine, Wisconsin, U.S.A., enabling the British company to manufacture the range of Webster model 1R and 2R oil-burner fuel units for sale in the U.K., Eire, Denmark, Sweden, Norway, South Africa, Australia, and New Zealand. The British product will be known as the Lee, Howl/Webster fuel injection pump, the two models being respectively single-stage and two-stage units.

* * *

Following the successful development of a range of hydro-pneumatic machine tools and units suitable for use in the light high-production industry for drilling, reaming and tapping, and multi-spindle work, **Slack & Parr Ltd.,** of Kegworth, near Derby, have made special arrangements to market these particular machines, as distinct from standard machines and drill-heads. As a result, the newly formed company of **Townsend-Coates Ltd.,** of 167 London Road, Leicester, have been appointed sole agents, and enquiries should be made directly to them.

* * *

Aveley Electric Ltd., of Ayron Road, Aveley Industrial Estate, South Ockendon, Essex, (Tel: South Ockendon 3444), have been appointed sole agents in the U.K. for the range of measuring, testing, and control instruments produced in Canada by the **Bach-Simpson Co.,** of London, Ontario. The instruments available to the British market will include multi-range test equipment, panel-mounted control indicators, frequency and running-time meters, educational instruments, radio and television service equipment, and a wide variety of portable meters and other instruments.

* * *

A reciprocal sales and manufacturing agreement has been concluded between **The Wayne Kerr Laboratories Ltd.** and **Gertsch Products Incorporated,** of Los Angeles, Cal. The agreement provides for the marketing and manufacture in the U.K. of a wide range of Gertsch electronic instruments by Wayne Kerr, and for the sale of Wayne Kerr instruments by Gertsch in California, Nevada, and Arizona. The principal Wayne Kerr instruments covered by the agreement include their SA100 transfer-function computer, transformer ratio

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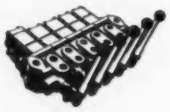

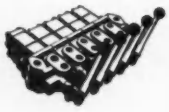

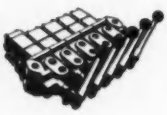

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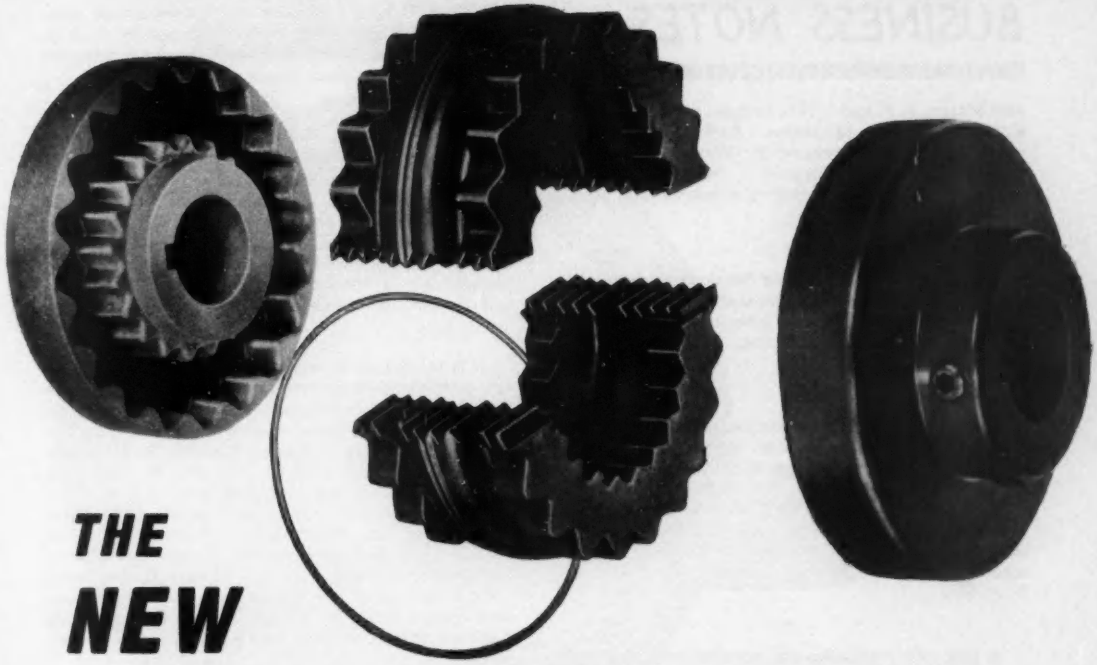

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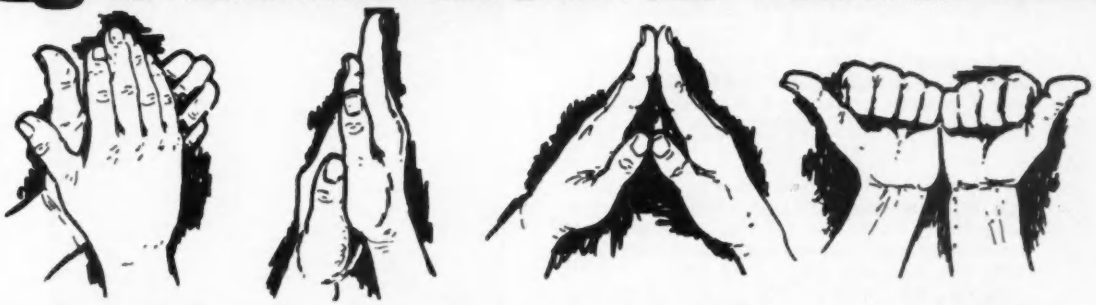

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BUSINESS NOTES

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* * *

It is announced by the **Lead Development Association** that they have vacated their previous offices at 18 Adam Street, London, W.C.2, and have now moved to new premises at 34 Berkeley Square, London, W.1 (Tel: GROsvenor 8422).

* * *

West Instrument Ltd., of Brighton, manufacturers of temperature-control instruments, have concluded agreements whereby they will act as U.K. agents for two American Companies, i.e., the **Radiation Electronics Corporation,** a division of the **Comptometer Corporation** and manufacturers of radiation thermometers and infra-red scanning systems, and the **RdF Corporation,** manufacturers of resistance thermometers and allied equipment.

* * *

A long-term marketing and manufacturing agreement has been made between **International Computers and Tabulators Ltd.**, of London, W.1, and the **National Data Processing Corporation,** of Dallas, Texas, whose advanced document-handling and optical character-recognition equipment are complementary to the punched-card and electronic-computer data-processing equipment produced by International Computers and Tabulators Ltd.

* * *

Tempered Group Ltd., of Sheffield, have acquired the entire issued share capital of **Henry Rossell & Son, Ltd.**, whose principal products are engineers' small tools, circular cutters, and machine knives.

* * *

It is announced that **Ipsen Industries Inc.**, of Rockeford, Ill., in association with **Ipsen Industries International G.m.b.H.**, of Kleve, West Germany, manufacturers of atmosphere and vacuum automatic heat-treating equipment and associated plant, have formed a British company, **Ipsen Industries Ltd.**, at 53 Victoria Road, Surbiton, Surrey, to facilitate further expansion of sales and service in the U.K.

* * *

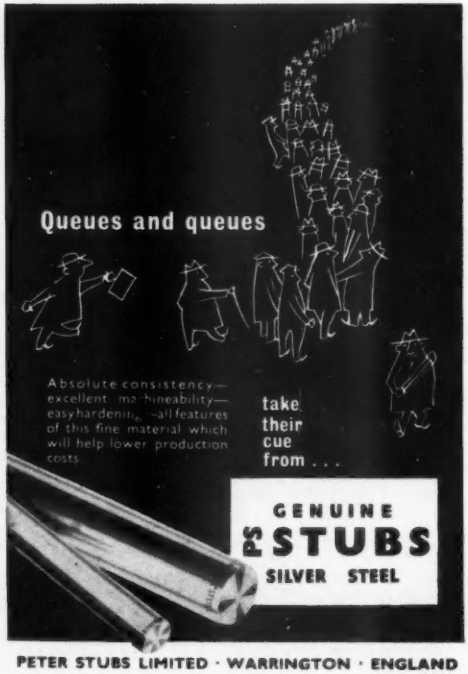
Following a recent agreement between the **Westinghouse Electric International Co.**, of New York, and **Hall-Thermotank Ltd.**, Westinghouse air-conditioning equipment will be marketed for the first time in the U.K. by the International Products Division of **Thermotank Ltd.**, who have opened offices at 60 Rochester Row, London, S.W.1, and who claim to offer the most comprehensive service from one source for the air-conditioning, heating, and ventilating industry. In addition to the new Westinghouse equipment, which includes self-contained conditioners with capacities ranging from 33,000 to 550,000 BTU/hr, the Division also market a wide range of air-conditioning products manufactured by **J. & E. Hall Ltd.**, by Thermotank Ltd., and by various companies in the Hall-Thermotank Group.

* * *

As announced by **Pye Ltd.**, of Cambridge, a new electronics factory will be opened at Inverigo, Northern Italy, and will be operated by a company to be called **Pye Electronic S.p.A.**, with offices in Milan. The new factory, which has a site area of about 150,000 sq ft, is now in production and it is expected that it will become the Pye Common-Market factory for the supply or manufacture of television, radio, domestic appliances, and electronic equipment.

* * *

It is announced by **Wickman Ltd.**, of Coventry, that a new company, **Schuler Presses Ltd.**, has been formed to manufacture certain Schuler presses in the U.K. and to provide a British-based engineering and after-sales service for all users of presses produced by **L. Schuler A.G.**, of Göppingen, Württ., Germany. Wickman Ltd. will act as exclusive sales representatives for the range of Schuler presses, including open-fronted, upright, and inclinable presses, double-sided eccentric, crank, and drawing presses, transfer presses, high-speed blanking and four-pillar dieing presses, knuckle-joint embossing presses, high-speed notching presses, dial-feed presses, and vertical cold-flow presses, as well as perforating machines and a complete tool-design and toolmaking service.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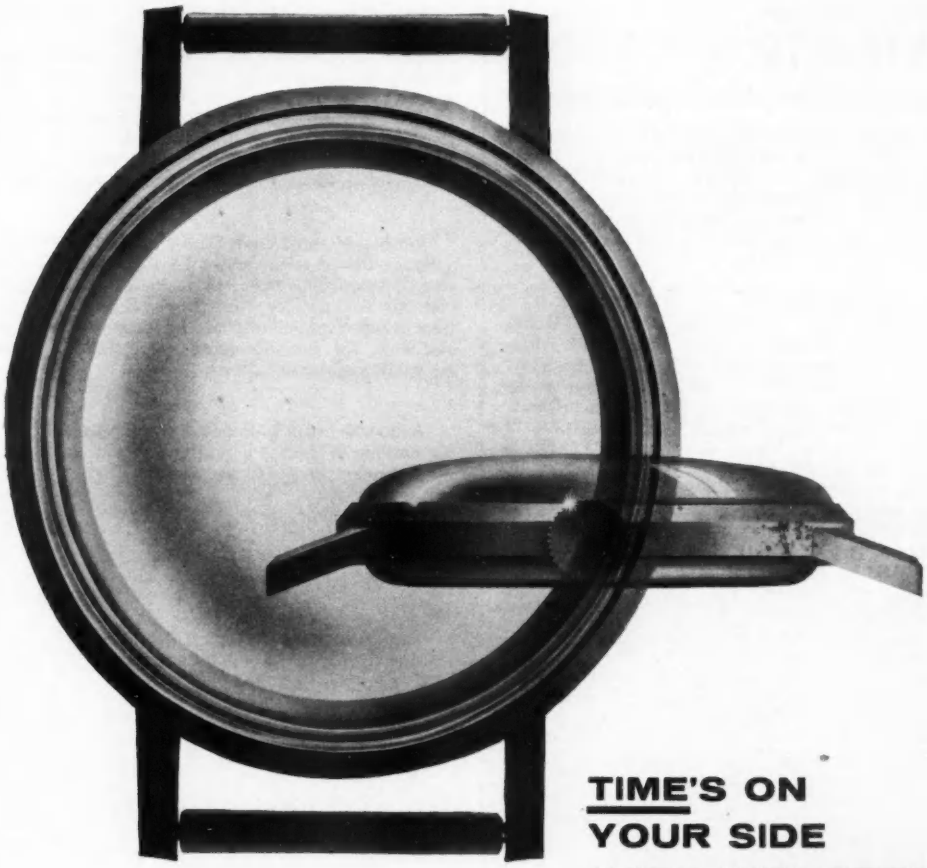

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The Industrial Diamond Information Bureau

2 CHARTERHOUSE STREET (DEPT 3.), LONDON, E.C.1.
Telephone: Fleet Street 7157

CONTRACTS

It is announced by The Federation of Civil Engineering Contractors that a contract, amounting to £1,750,000, for the construction of six large natural-draught cooling towers for the Drakelow "C" power station at Burton-on-Trent has been awarded to Film Cooling Towers (1925) Ltd. The contract will be carried out in partnership with J. L. Kier & Co. Ltd.

* * *

Following orders to the value of about £930,000, received during the past few weeks from South Africa for A.E.C. passenger and goods chassis, a further order for vehicles has now been received from South Africa by A.E.C. Ltd. The new order, which amounts to nearly £290,000, involves more than 60 chassis, including 27 bonneted "Mammoth Major" six-wheelers, 11 forward-control "Mammoth Major" six-wheelers, and 14 bonneted "Mammoth" four-wheelers, all of which will be powered by the A.E.C. 11·3-litre diesel engine. The balance of the order is made up of passenger chassis, including 8 "Regal" Mk. IV single-deck bus units.

In addition, the Australian branch of Transport Equipment (Thorneycroft) Ltd. has received a repeat order for 10 "Nubian" 6 × 6 high-performance chassis for fire crash-tenders, the bodywork and equipment being supplied by Wormald Bros. (Vic) Pty. Ltd. to the requirements of the Australian Department of Civil Aviation. These crash-tenders feature a roof-mounted foam monitor having a discharge rate of 4000 gpm. This order brings the total number of "Nubian" vehicles supplied to Wormald Bros. up to 55, of which 26 will be operated by the Civil Aviation Authority and 29 by the Royal Australian Air Force.

* * *

A contract valued at over £66,000 has been obtained by Bennis Combustion Ltd. for the supply and installation of a mechanized ash-handling plant at the Kearsley Power Station of the Central Electricity Generating Board. The plant, which will replace an old monorail bucket system, will quench and convey ash from 16 water-tube boilers to a reinforced-concrete bunker of 350 tons capacity. The conveyor system comprises 25 belt conveyors, of which 8 are of the submerged type for quenching the hot ash. Riddlings from the boilers are collected on dry belt conveyors and join the quenched ash at a central point, from which it is all taken by an inclined belt conveyor to the bunker. The whole system is automatically controlled from a central panel and has a capacity of 56 tons of dry ash per hour.

* * *

An order to the approximate value of £5,000,000 has been placed by the British Transport Commission with The Clayton Equipment Ltd., a member of the International Combustion (Holdings) Ltd. Group, for 88 Type-1 diesel-electric locomotives. These locomotives will have a central cab and will be provided with twin generating sets, one at each end, for operation on one or both sets. Two Paxman engines, each of 450 hp, will be fitted, and the electrical equipment will be supplied by The General Electric Co. Ltd.

Two contracts, with a total value of about £150,000, have been received by A. Reyrolle & Co. Ltd., of Hebburn, Co. Durham, from the Hydro-Electric Commission, Tasmania, for the Poatina hydro-electric power station. The first contract is for eight 220-kV, 5000-MVA air-blast circuit-breakers, current transformers, and ancillary equipment, while the second contract is for thirteen 110-kV, 3500-MVA small-oil-volume circuit-breakers with transformers and ancillary equipment.

* * *

Renault Machine Tools (U.K.) Ltd., of Shrewsbury, a wholly owned subsidiary of La Régie Nationale des Usines Renault, of Paris, has successfully negotiated a £200,000 contract for the supply of Renault in-line transfer machines and ancillary machines to be designed and built for the high-speed production of Hobbs automatic transmissions for motor-cars.

* * *

A £40,000 contract for the supply of materials for and the erection of a 132-kV grid link in Lincolnshire has been awarded to Associated Electrical Industries Ltd., whose Construction (Cables and Lines) Division will carry out the work for the Central Electricity Generating Board, North Eastern Region. The contract involves a 6¼-mile steel tower line connecting a new 132/33-kV substation to be built at Blyton, 10 miles south of Scunthorpe, and the existing Keadby-Wold Newton 132-kV line at a point near Messingham. Initially, only one circuit is to be erected on the new line, which is scheduled for completion in the summer of 1962.

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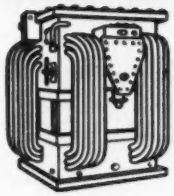
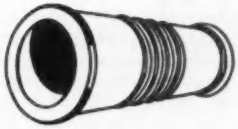


from transformers

to bellows



the relief of stresses demands

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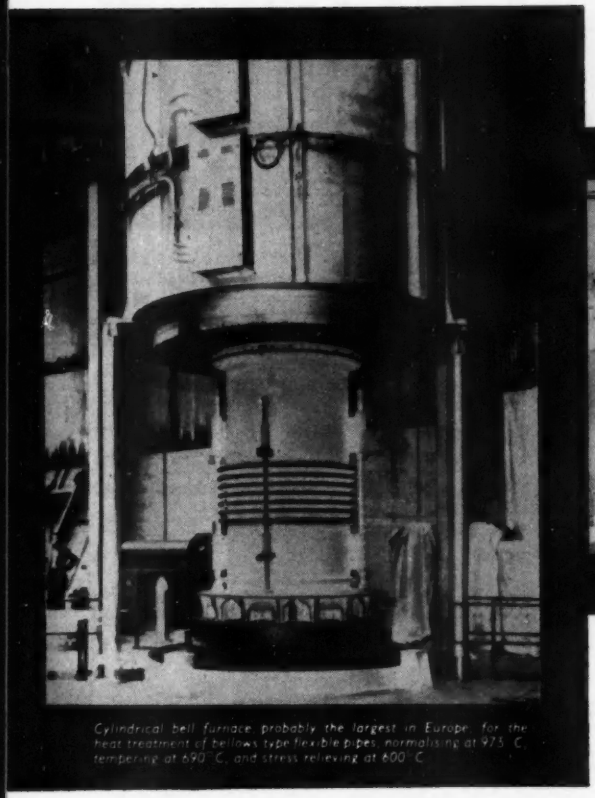

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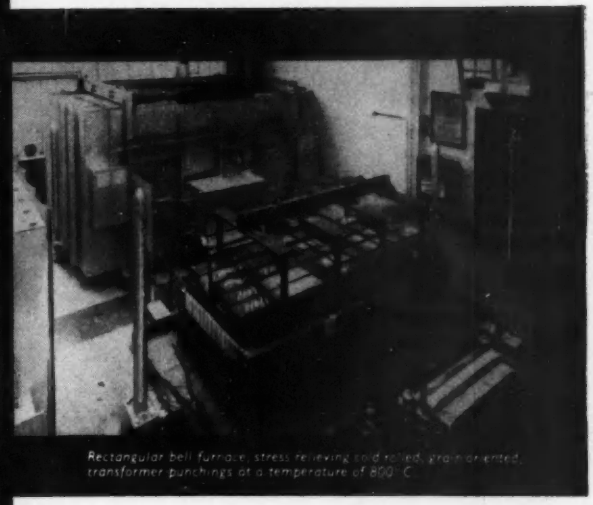

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PERSONAL

Keith Blackmann Ltd. announce that **Mr. D. S. Woodley, M.I.Mech.E., M.I.H.V.E.,** retired from the office of managing director on May 31, 1961, and was succeeded by **Mr. F. W. Goodge,** one of the present joint assistant managing directors, while **Mr. C. J. Atkins** became assistant managing director.

* * *

Mr. N. E. N. Plahn, managing director of Fuller Electric Ltd., has been appointed to the board of Hawker Siddeley Industries Ltd. Mr. Plahn was appointed a director of Fuller Electric Ltd. in 1932 and managing director in 1955.

* * *

It is announced by The Electrical Research Association that **Mr. J. E. Beard, C.B.E.,** will be its next president. Mr. Beard is the senior partner in Merz and McLellan, consulting engineers, and is known internationally for his work in the electrical field.

* * *

Mr. V. M. G. Bennett has been appointed to the board of Teddington Aircraft Controls Ltd., and will be divisional director in charge of the sales of the aircraft and the bellows divisions.

* * *

It is announced that **Mr. G. G. Thompson** has been appointed a director of the Birmingham Chemical Co. Ltd., of Lichfield, a member of the Staveley Group of companies. Mr. Thompson is on the board of the parent company, Staveley Industries Ltd., and is managing director of the British Soda Co. Ltd., of Sandbach, another member of the group.

* * *

Mr. R. T. Pemberton has been appointed to the board of Stone-Platt Industries Ltd., of London, S.W.1. **Mr. F. G. Hawkings** has been appointed managing director, and **Mr. E. G. Smalley** deputy managing director, of Textile Machinery Makers Ltd., a Stone-Platt subsidiary.

* * *

Thor Tools Ltd., formerly Armstrong Whitworth (Pneumatic Tools) Ltd., announce that **Mr. C. B. Bergren** has been appointed managing director. Mr. Bergren, a qualified engineer, was formerly manager of Thor Industrial Sales, operating from Aurora, Ill., U.S.A., and succeeds **Mr. R. G. Faverty,** who is returning to the U.S.A. as vice-president of the parent company.

* * *

Mr. H. T. Jenkins, B.A. has been appointed technical director, and **Mr. J. S. Waring** production director, of Robert Jenkins & Co. Ltd., of Rotherham.

* * *

Darchem Engineering Ltd., a member of the Darlington Chemicals Group, announce that **Mr. A. B. Miles,** formerly chief draughtsman, becomes chief engineer of

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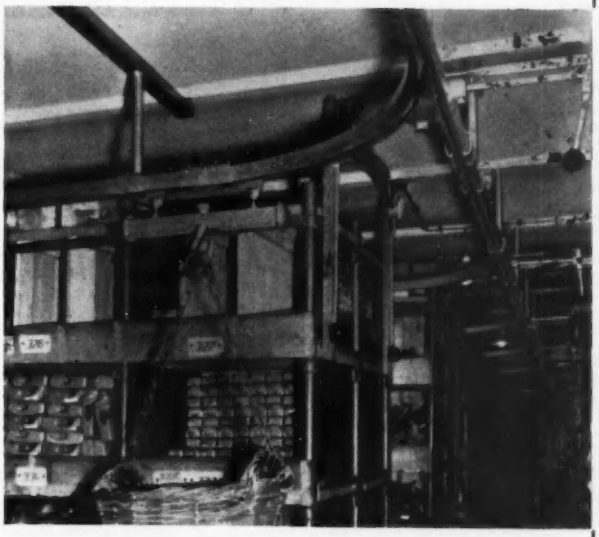

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PERSONAL

the company, while **Mr. F. Meadows,** formerly assistant chief draughtsman, succeeds Mr. Miles as chief draughtsman. In addition, **Mr. D. A. Rowlett, M.Sc.(Eng.) London,** has been appointed manager of the Rostenit (stainless-steel lining process) division.

* * *

Mr. R. A. Bones, B.Sc., Ph.D., A.Inst.P., has joined The Wayne Kerr Laboratories Ltd. as head of the company's Contracts Division.

* * *

Mr. L. R. Blake, Ph.D., B.Sc.(Hons.)Eng., A.M.I.E.E., has been appointed to the new post of director of engineering at the Brush Electrical Engineering Co. Ltd., and has joined the board as an executive director.

* * *

It is announced by Associated Electrical Industries Ltd. that **Mr. N. Elce, M.Sc.(Tech.), M.I.Mech.E., F.R.S.A.,** director and chief mechanical engineer of Associated Electrical Industries (Manchester) Ltd., has retired after 41 years with the A.E.I. group of companies and has been appointed consultant to the managing director at Manchester. **Mr. D. W. Evans, A.M.I.E.E.,** assistant sales manager, Traction Department (Rugby), A.E.I. Traction Division, has retired after 40 years of service. **Mr. G. F. Gribbin, B.Sc., A.M.I.E.E.,** has been appointed sales manager of the A.E.I. X-ray Department.

* * *

Staveley Industries Ltd. announce that **Mr. J. E. Abel,** sales manager of George Richards & Co. Ltd., of Altrincham, a member of the Staveley Group, has been appointed a director.

* * *

As announced by Imperial Chemical Industries Ltd., **Mr. T. H. Gallie** has been appointed overseas director, and **Mr. J. R. H. Crane** director in charge of copper products, of I.C.I. Metals Division.

* * *

Mr. J. D. Stevenson has been appointed manager of aero sales of the Sperry Gyroscope Co. Ltd., London, filling the vacancy created by the recent posting to Sperry Europe Continental, Paris, of **Mr. C. A. Richardson** as director of export sales.

* * *

It is announced by Airmec Ltd. that **Mr. J. C. Simmonds, M.Sc.(Eng.), Ph.D., M.I.E.E., M.I.Mech.E.,** has been appointed to the board of Thermionic Products Ltd. Dr. Simmonds is also managing director of the British Communications Corporation and deputy managing director of Radio and Television Trust Ltd.

* * *

Mr. J. Gombinski has been appointed managing director of E. G. Brisch & Partners Ltd. In addition, **Mr. H. R. Whitty** has joined the board of the company.

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OF HYDRAULIC HOSE FEED LINES
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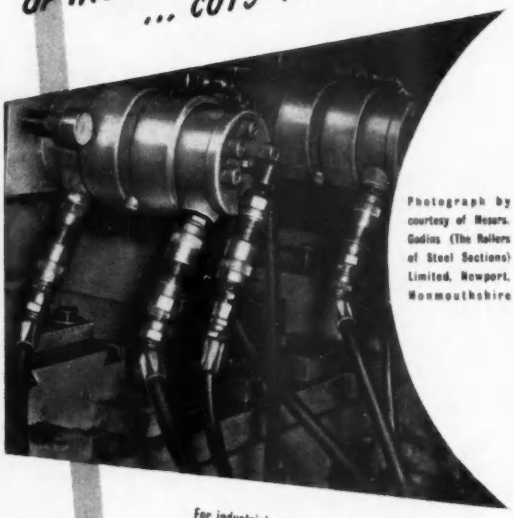

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NEWS ROUND-UP

Automatic Control of Television-Tube Plant

Believed to be the most advanced production line for television-tube glassware in the world, a new fully automatic plant has been commissioned at the Simonstone Works of Mullard, near Burnley, Lancs., and is based on a similar installation at the Eindhoven Works of Philips in Holland. Automatic control, from the melting stage to the final conditioning zones, precisely governs the temperature, viscosity, and homogeneity of the molten glass.

The control instrumentation, by Honeywell Controls Ltd., of Greenford, Middlesex, provides for completely automatic operation, maintaining the accuracy and stability essential to the successful high-throughput production of glass in continuous units. Glass level is controlled to an accuracy of 0·005 in. and feeder temperatures to within 0·5°C. Molten-glass level, fuel-oil and air inputs, furnace pressure, regenerator differentials, and glass feeder temperatures are the principal controls handled by a central control panel, which is 60 ft in length and is equipped with about 30 instruments. Of these, Philips have supplied a number of multi-point temperature recorders, George Kent Ltd. oxygen-analysing and recording equipment, and Electroflo Meters Ltd. a furnace-pressure recorder.

Multi-Weld Lines for Motor-Car Underbody Assemblies

In the mass production of modern integral motor-car body shells, a serious problem is the production of consistently accurate car underbody assemblies from separate assemblies. It is now reported, however, that this problem has been overcome at the Dagenham factory of the Ford Motor Company by installing multi-weld lines, the first of which is already in use. A second line is nearing completion and a third is under way, each line being capable of producing underbody assemblies at the rate of one per minute.

In operation, the separate parts are loaded into ten jig frames and passed through a series of five presses, each making about 150 spot-welds between the floor pans and the floor-frame members. Loading is effected at three stages, where a small amount of portable or hand-welding is used to tack the assembly together. Each press consists of a base, a platen, and a crown, supported on the base by four columns. The platen moves up and down hydraulically to bring the component into contact with the welding guns suspended from the crown. The guns are composed of a hydraulic cylinder with a water-cooled electrode connected to the end of the piston rod. The components are "backed up" underneath the guns by copper blocks which contain separate copper electrodes, so that they can be clamped together at the spot where the weld is to be made. These back-ups reproduce the shape of the components and are mounted on the bottom bolster of the tool, which, in turn, is secured to the top face of the platen.

It is usual in series welding to have four guns per transformer, each gun producing one spot-weld but, owing to the large number of welds, the number of transformers required would be excessive. A method of

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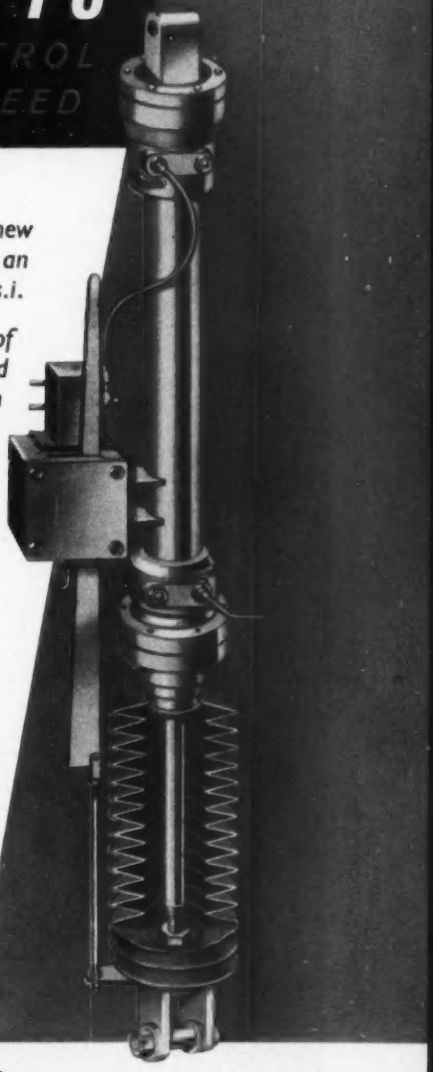
NEW

HYDRAULIC PNEUMATIC

POSITIONAL-CONTROL UNITS BY LOCKHEED



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indexing the welding guns was therefore devised so that each gun could perform as many as four welds, reducing the number of transformers and making it possible to achieve a closer pitch between spots than the guns would normally allow. As each weld is completed the index of the gun is motivated, and, when a sequence is ended, the platen descends, causing the transfer mechanism to move the jig into the next stage. The jig frame is transferred from one stage to another by a friction drive automatically operated by electrical limit-switches. These switches are set off by the preceding operation, and are in turn connected to solenoid-actuated air valves which control air cylinders on the drive wheels, etc. When welding has been completed in the fifth press, the jig frame is transferred to a lift, where two beams move between the component and the jig frame. The lift is then free to descend, taking the jig frame with it for return underground to the loading stage. Meanwhile, the underbody is transferred to the turnover mechanism, turned through 180 deg., and deposited on a conveyor for inspection and subsequent work.

Institution of Electronics Exhibition and Convention

The sixteenth annual Electronics, Instruments and Components Exhibition and Convention of the Institution of Electronics will be held at the College of Science and Technology, Manchester 1, between July 6 and 8, and July 10 and 12 inclusive. The exhibition and convention will incorporate a scientific and industrial research section, a manufacturers' section, and a programme of lectures and films on electronics, instruments, and components.

Complimentary admission tickets to the exhibition can be obtained, on forwarding a stamped addressed envelope, from the exhibitors or from Mr. W. Birtwistle, General Secretary, The Institution of Electronics, 78 Shaw Road, Rochdale, Lancs. A "Preview of the Exhibition and Convention" (post free 6d) and free lecture admission tickets are also available. Catalogues (post-free 3/6) will be available at the end of June 1961.

New Design of Surface Condensers for Steam Turbines

The Central Electricity Generating Board is placing an order worth £1,500,000 with Associated Electrical Industries Ltd. for four surface condensers for use in association with four 500-MW steam turbines in one of the new Midlands power stations. The total heat-transfer surface in each condenser will amount to 300,000 sq ft, and cooling water will be circulated at 200,000 gpm.

The new condensers are of novel design and are stated to mark a significant advance in the development of units intended to handle large quantities of exhaust steam from very large turbines. Thus, condensers are traditionally placed transversely in the turbine foundations, makihg it impossible to provide turbines with continuous supporting walls—an important factor in view of the rapid increase in the unit size of power-generating plant—while the increasing number of exhaust flows in these large machines has necessitated the use of

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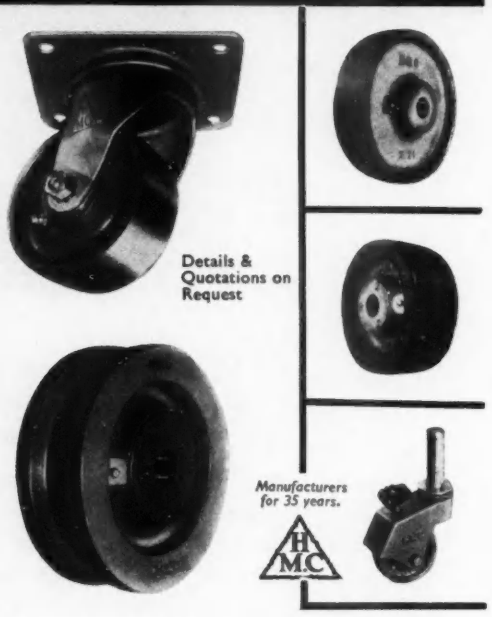

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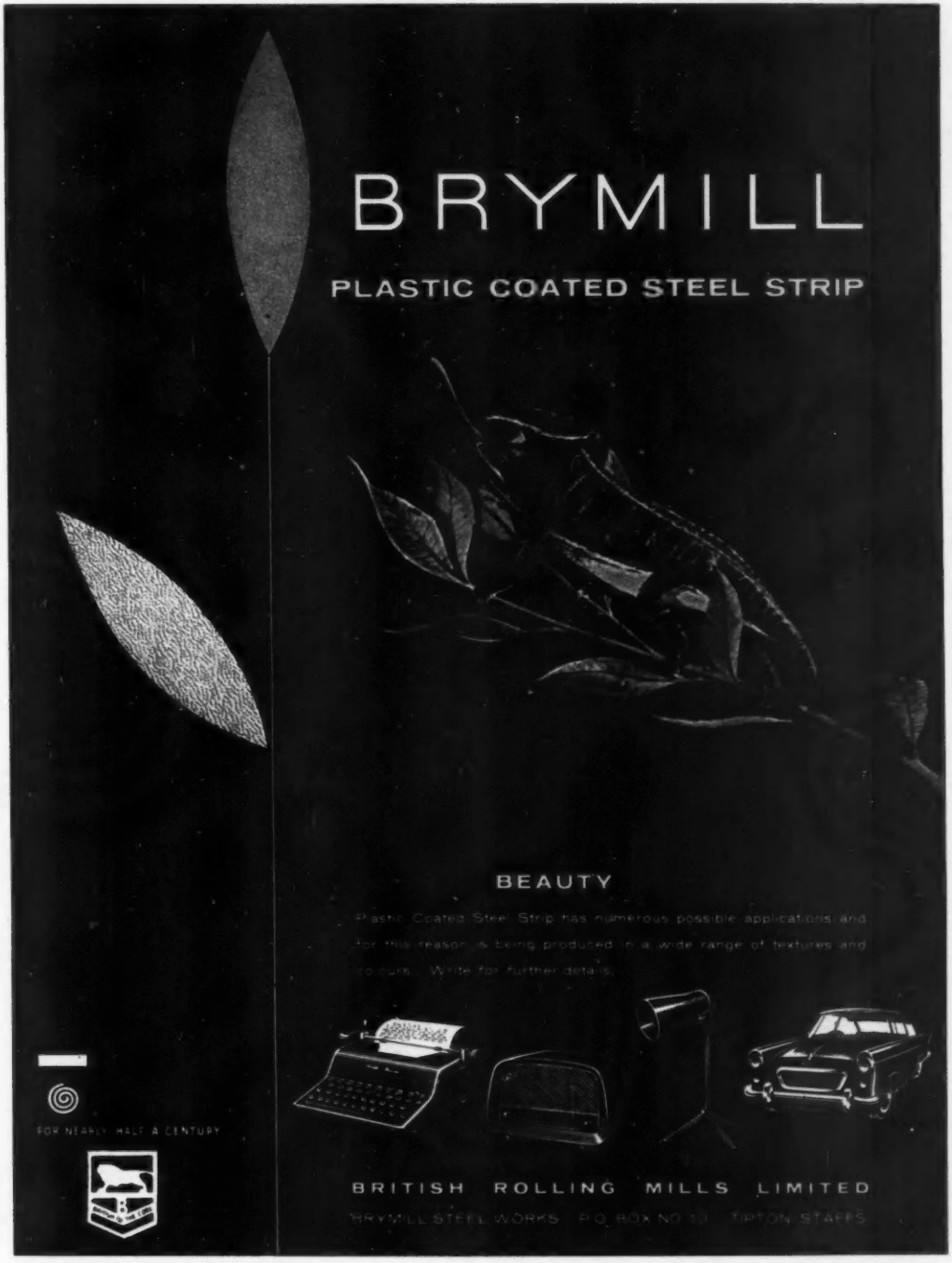
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two or even three condenser shells. On the other hand, the new A.E.I. condensers have been designed to overcome this problem by using single-shell units which will be arranged parallel to the turbine axis and housed within the foundation-block supporting walls. This arrangement has made it necessary to employ a single water-pass in the condenser tubes and, although it has the advantage of making the condensers lighter and more compact, it has also presented special technical problems of its own, notably in connection with differential heat flow between the two ends and efficient de-aeration of the condensate. These problems have been successfully overcome and, insofar as de-aeration is concerned, the condensate flow path has been arranged in such a way that a degree of de-aeration equal to that obtained in the best two-pass units is expected.

The fact that air and incondensible gases have a lower rate of heat transfer than wet steam has been provided for by the use of multi-pass water flows in the section of the tube-nest where they are concentrated. As a result, it is expected that there will be a significant saving in cooling-water requirements, which should be appreciably lower than those in conventionally designed condensers of similar capacity. The new design incorporates twin tube-nests and, in accordance with normal practice, provision has been made for separate air extraction from each nest, permitting cleaning of one nest while the other is in commission.

The 1961 Convention of The British Institution of Radio Engineers

For their 1961 Convention, The British Institution of Radio Engineers has taken "Radio Techniques and Space Research" as their theme. In this connection, the decision of the Institution to hold the Convention, which will take place in Oxford University from July 5 to 8, 1961, has been influenced by the value of discussion on the techniques and possibilities for satellite communications to those concerned with the "European Space Launcher Club". In addition to the use of satellites for communications, the Convention will discuss research projects such as those which are to be carried out in the British satellite scheduled for launching by the American "Scout" rocket towards the end of this year. Other papers will deal with radio astronomy, which has played such a notable part in conjunction with both research and communication satellites and with satellite tracking.

About fifty papers will be read and contributions will be made by authors from many countries. While emphasis will be laid on British and Commonwealth achievements and proposals, papers from European countries will also be read, and several specially invited contributions will be made by leading authorities from the U.S.A. and the U.S.S.R. Similarly, participation in the Convention will be international, and some 500 delegates are expected to attend.

An important group of papers will deal with various aspects of launching satellites and with the consideration of satellites themselves. This latter subject calls for the solution of problems in electronic engineering which have drawn upon experience gained in very different fields, in which component techniques developed for use in underwater telephone repeaters, in business computers, and in nuclear reactors all play their part. Conversely, it may be expected that many of the techniques described, which have been specially developed for use in satellites, will eventually find application on earth.

Monks and Crane Exhibition of Machine Tools

Staged in the specially constructed showroom at their head office in Garretts Green Lane, Sheldon, Birmingham, the "Machine-Tool Fortnight" exhibition organized last month by Monks and Crane Ltd. spotlighted machines and tools from Sweden, Germany, the U.S.A., and the U.K. In addition, a regular programme of films was shown, including "The World Turns" by the Colchester Lathe Co. Ltd., "Versamatic" by the Supreme Products Corporation, and "The Silent Enemy" by the Rust-Oleum Co. Ltd.

The exhibition featured 50 different machines, all of which are being distributed by Monks and Crane Ltd., together with a wide range of tools. New items, featured in Great Britain for the first time by the company, included the Swedish-made "Rosenfor" lathes and milling machines, and "Arboga" bench, pillar, and radial drilling machines, small milling machines, and general tool grinders. Other machines included Smart and Brown portable screwing machines, which are specially designed to be moved easily by pipe-fitters from one part of a factory to another, and two German "Forte" horizontal bandsaws. Of these, the Model 250 is a general-purpose machine designed for cutting off round bars up to 10 in. in diameter or rectangular sections up to 10¼ in. × 17¾ in. The second machine is the "Fortemat" Model BA.251, which is a more elaborate version of the Model 250 machine and fully automatic, requiring no further attention after loading and setting until the bar is completely exhausted. New American equipment included a wide range of "Supreme" geared-key, keyless, tap, and impact chucks, chuck arbors and keys, and power-tool attachments.

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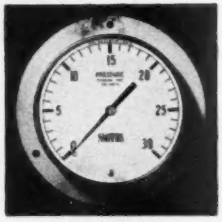

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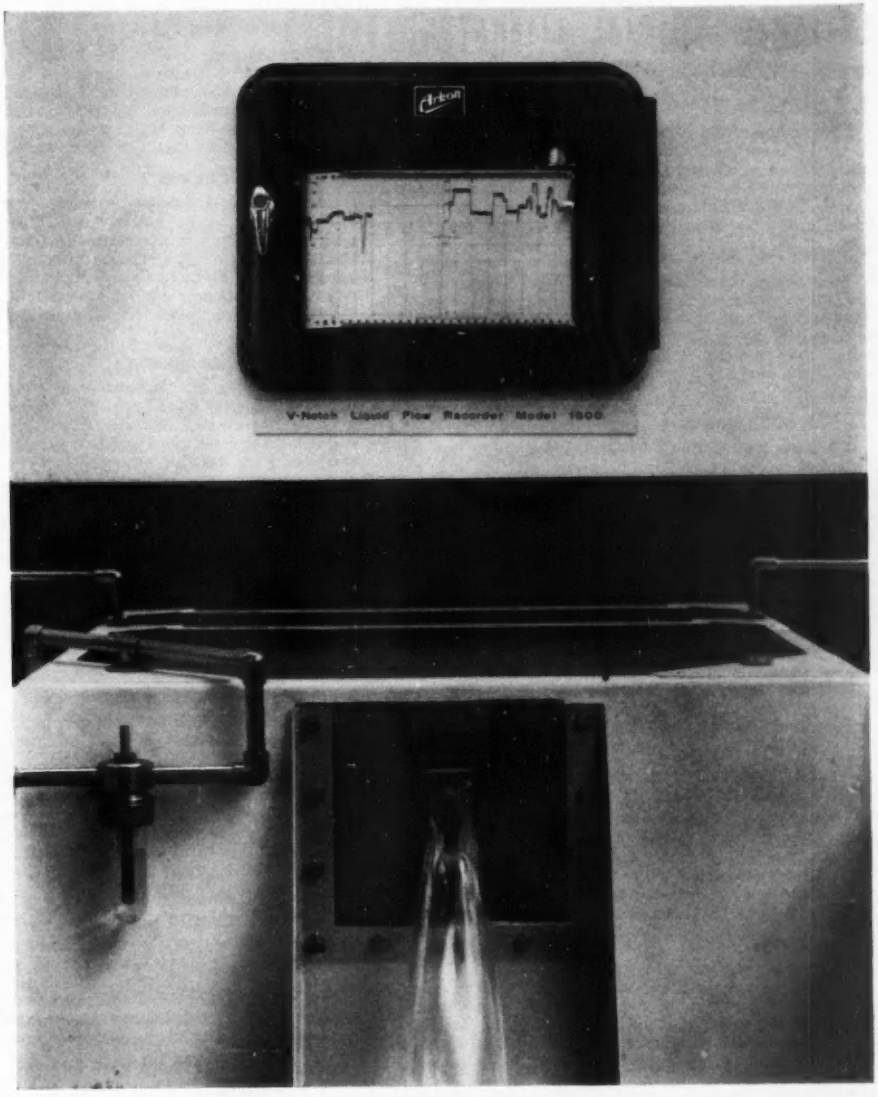

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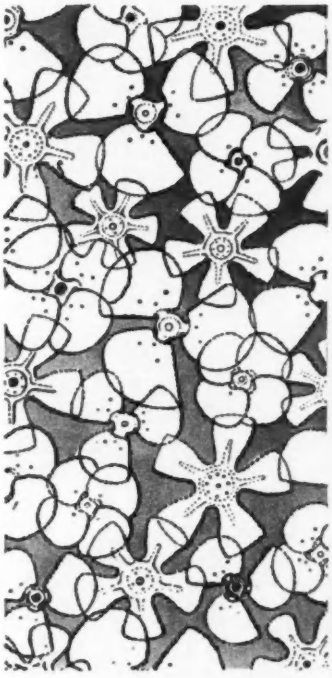

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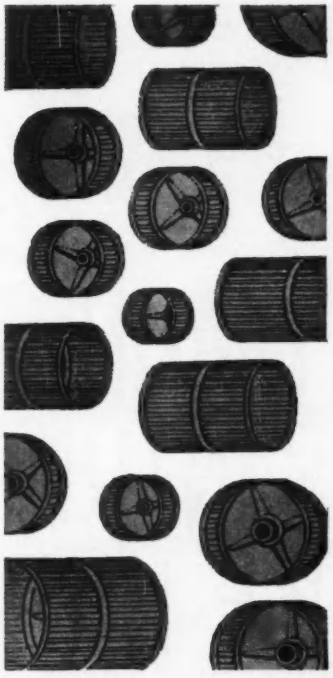

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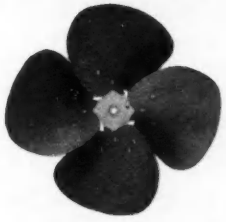

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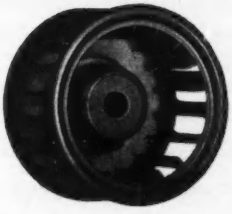

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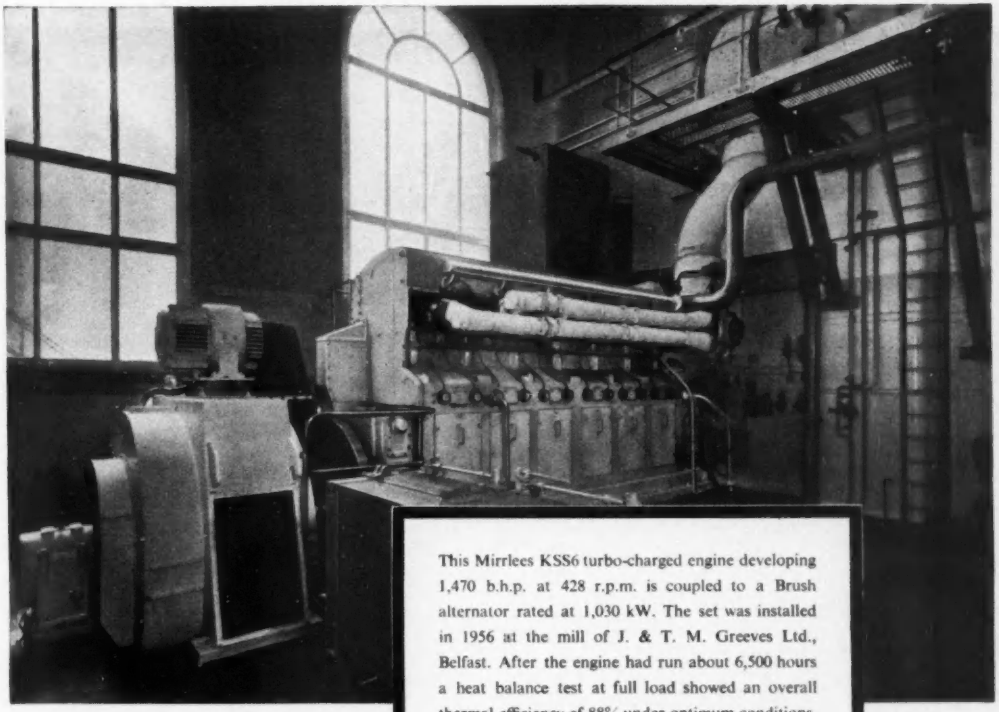

This Mirrlees KSS6 turbo-charged engine developing 1,470 b.h.p. at 428 r.p.m. is coupled to a Brush alternator rated at 1,030 kW. The set was installed in 1956 at the mill of J. & T. M. Greeves Ltd., Belfast. After the engine had run about 6,500 hours a heat balance test at full load showed an overall thermal efficiency of 88% under optimum conditions.

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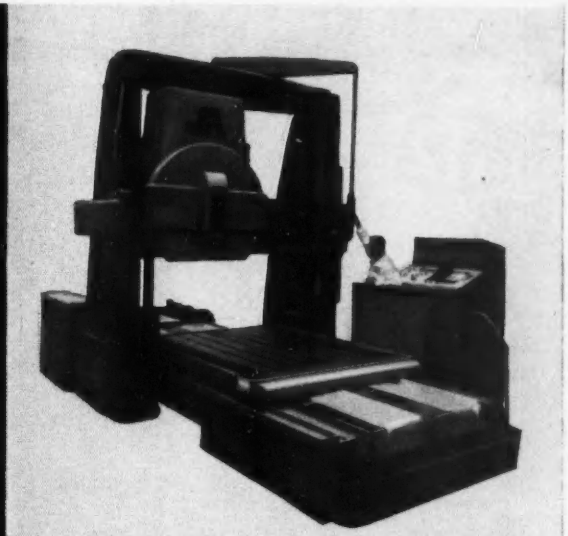

The quick response of Warner Clutches makes them eminently suitable for use in the positioning gear-boxes of James Archdale's new "Autonomic" Vertical Co-ordinate Drilling Machine on which the drilling head and table are accurately positioned under automatic control.

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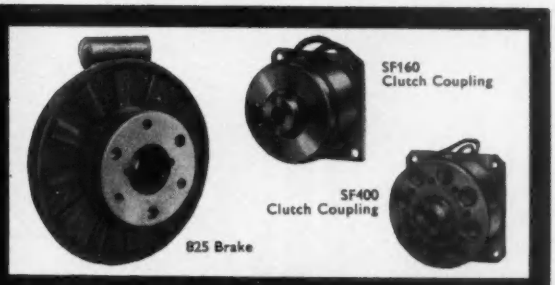

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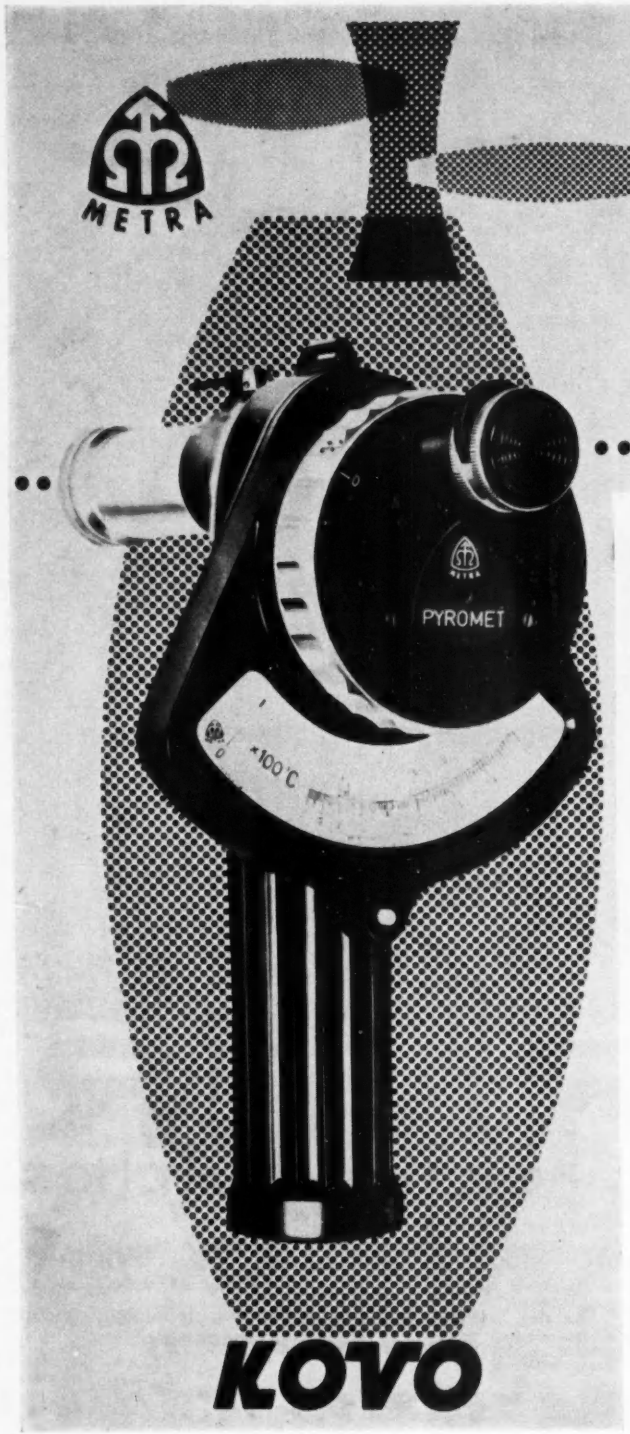

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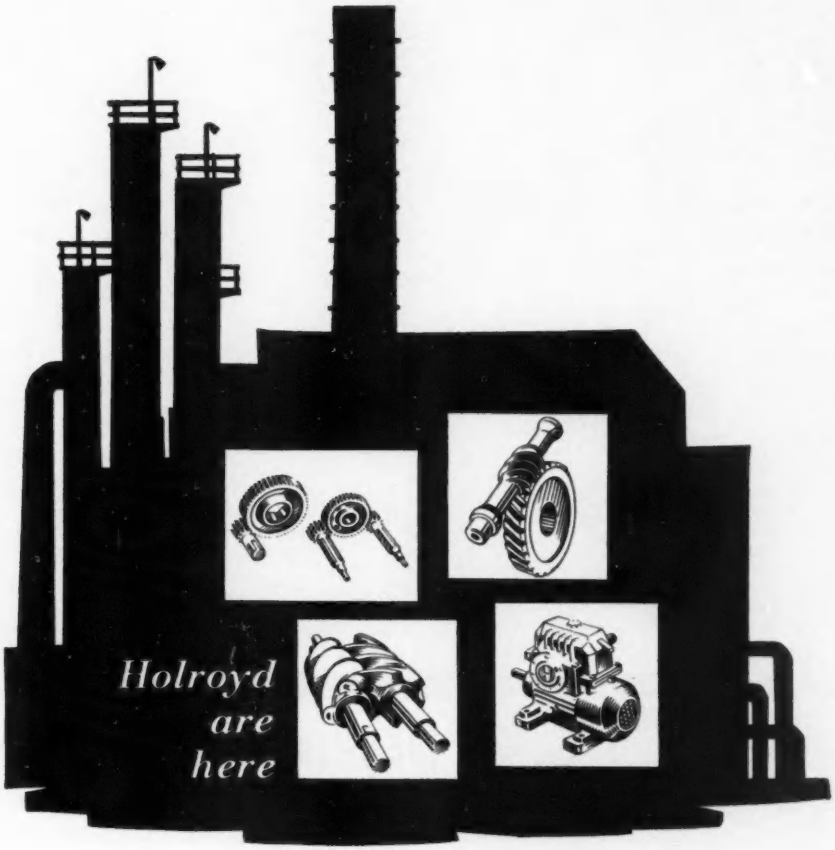

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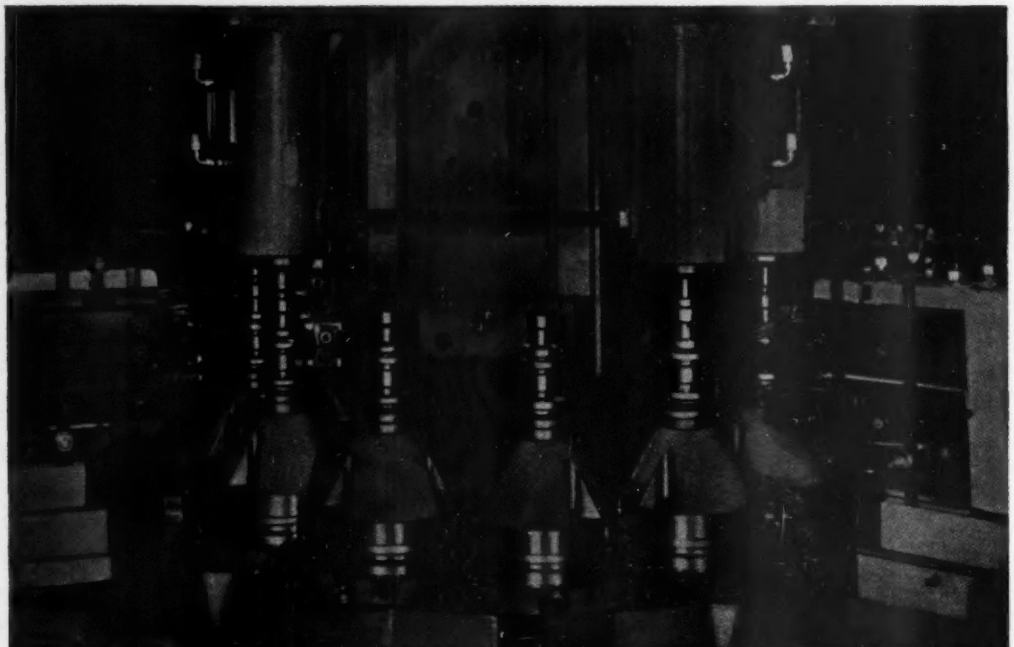

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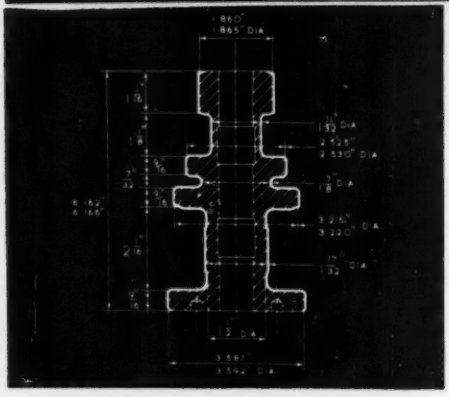

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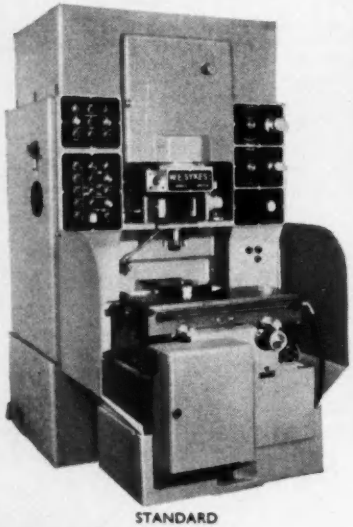

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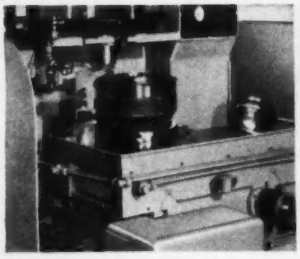

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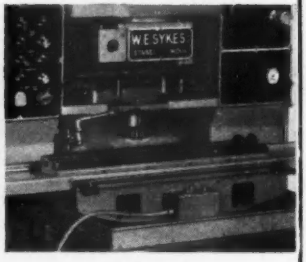

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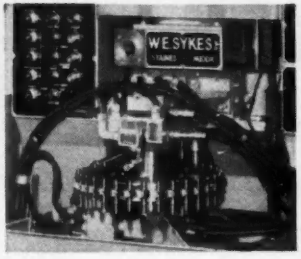

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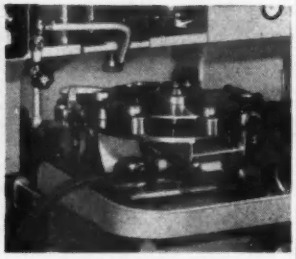

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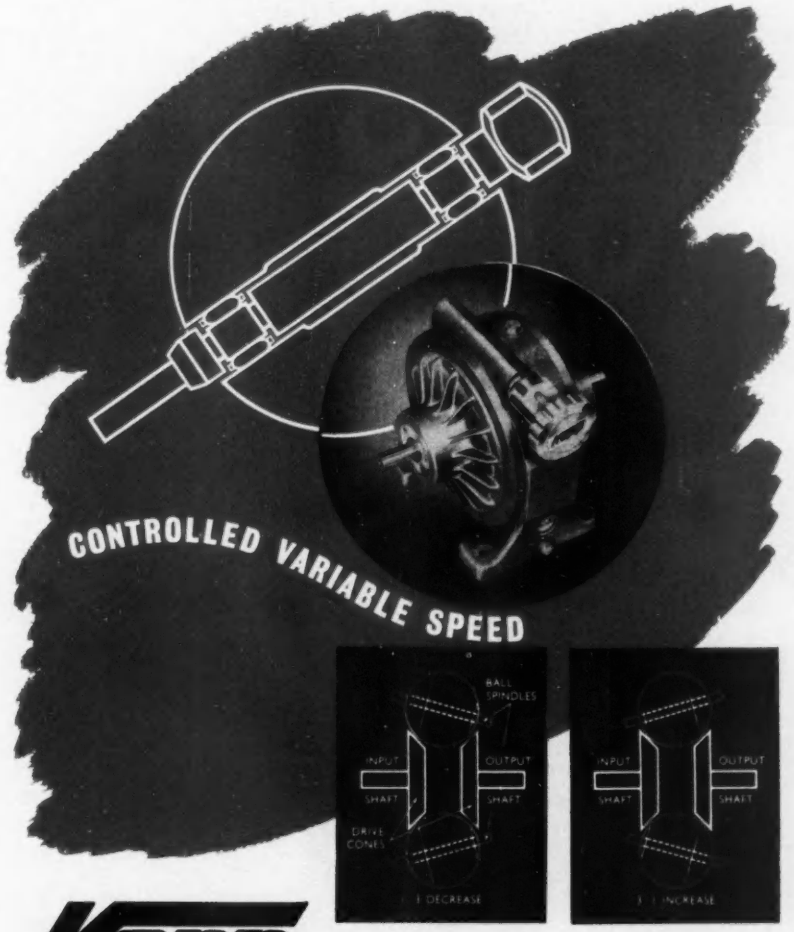

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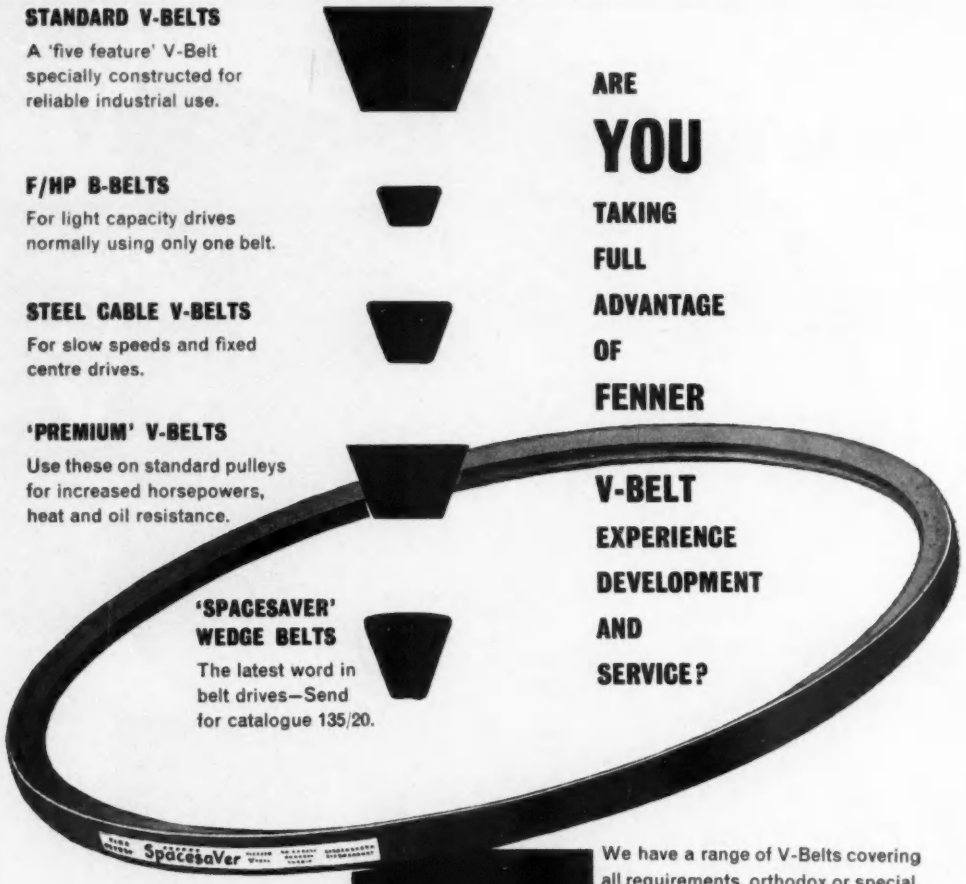

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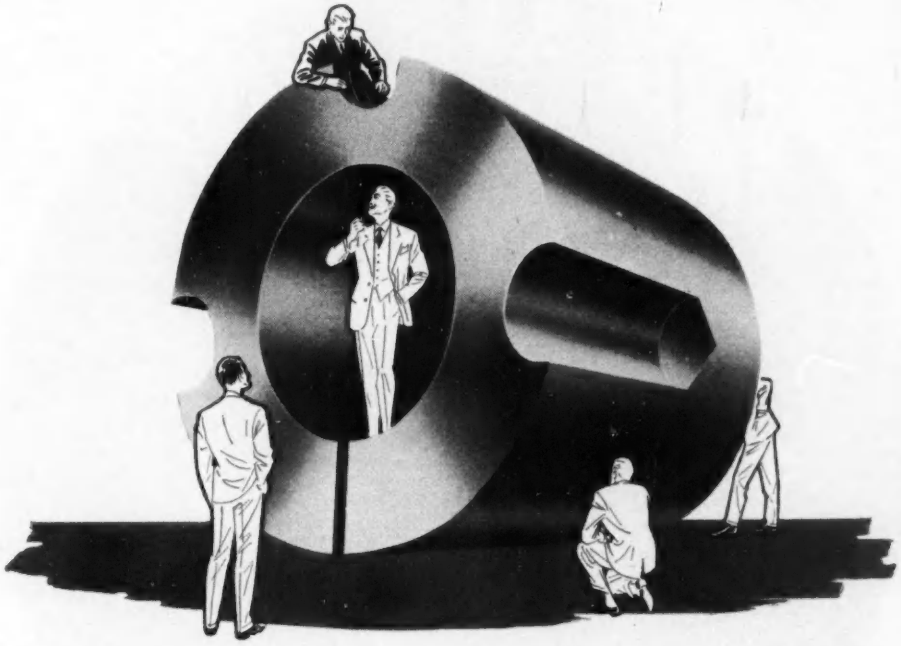

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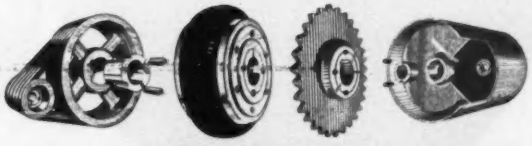

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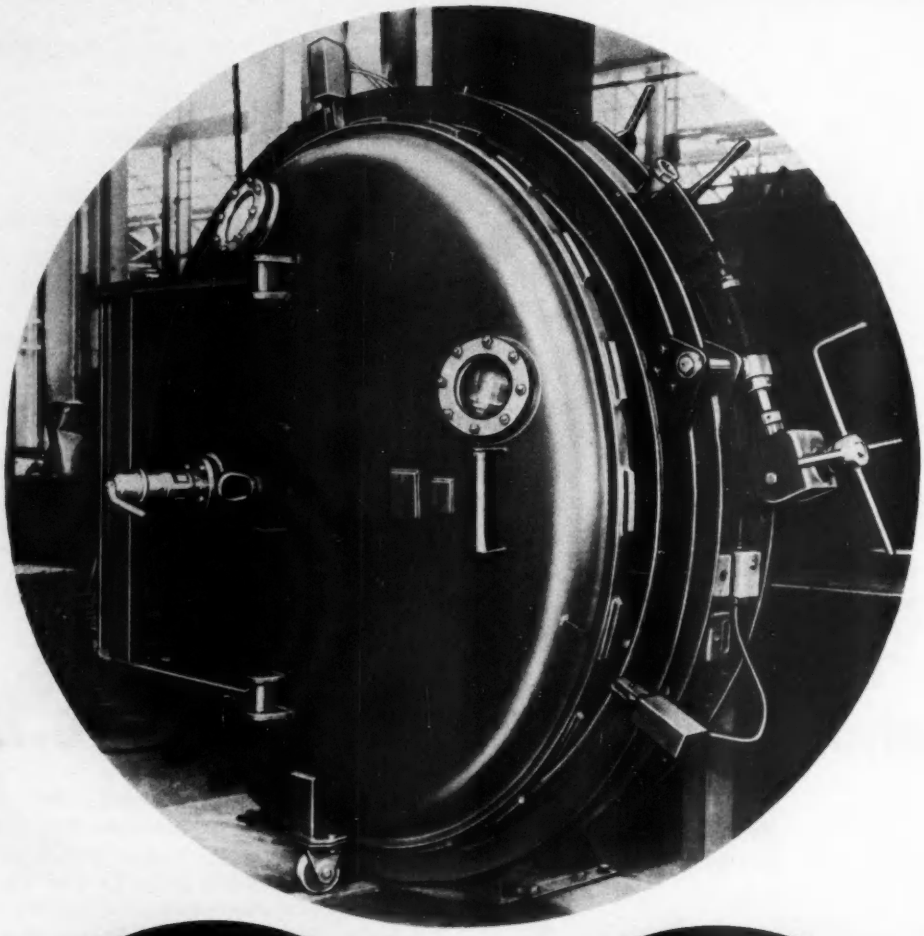

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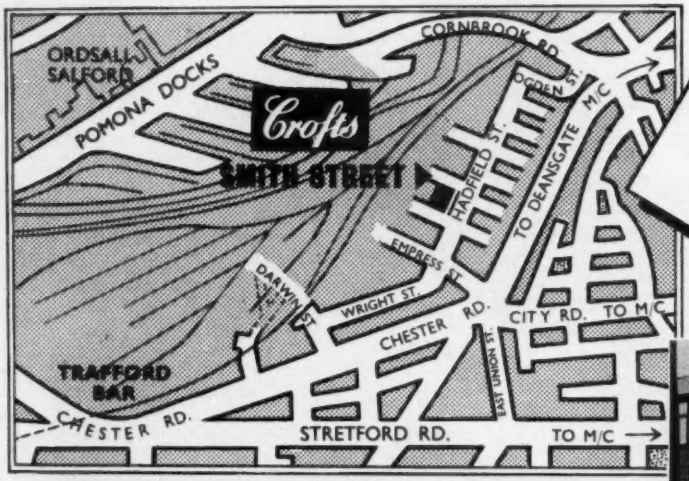

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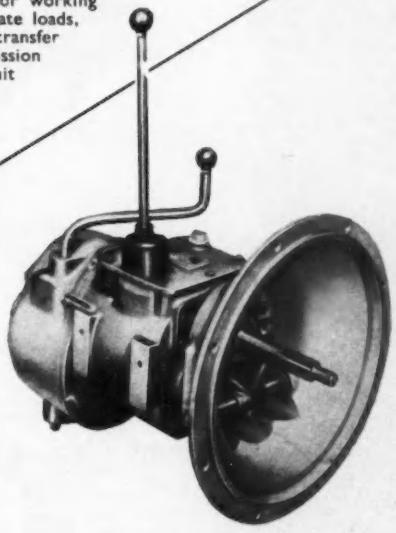

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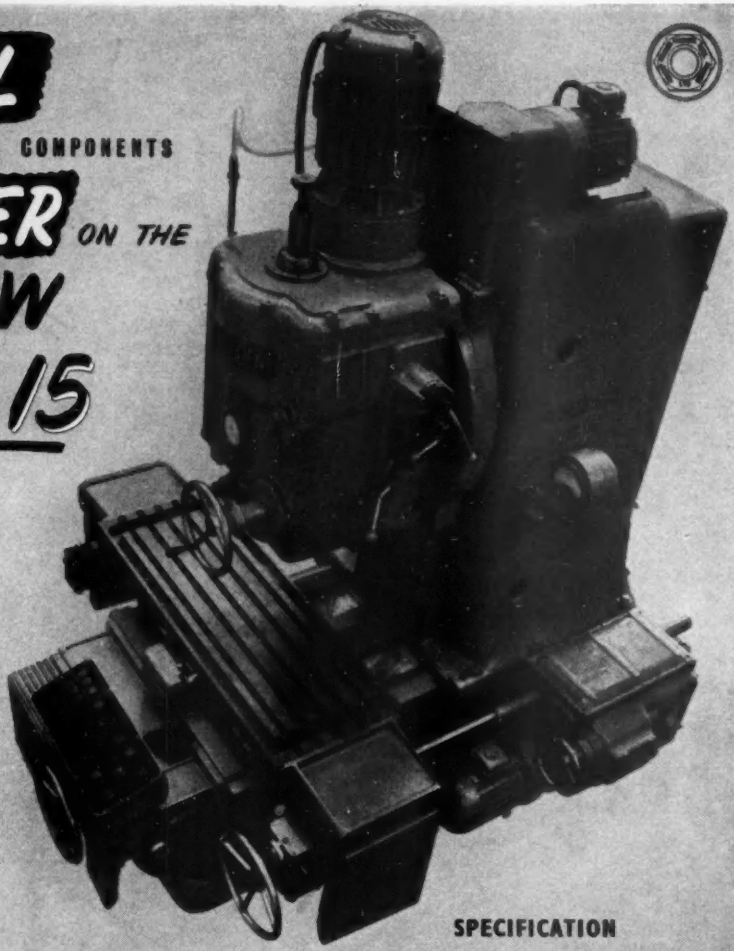

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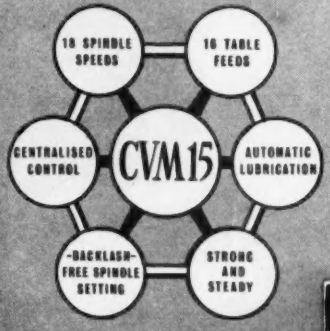

SPECIFICATION

WORKING SURFACE OF TABLE		54 in. x 16 in.
HEIGHT ADMITTED BETWEEN SPINDLE NOSE & TABLE	MIN.	1½ in.
	MAX.	24 in.
DISTANCE FROM CENTRE OF SPINDLE TO FACE OF COLUMN		18 in.
SPINDLE ADJUSTMENT		6 in.
SPINDLE DRIVING MOTOR		40 h.p.
SPINDLE SPEEDS: up to 1600 r.p.m.		
THREE OPTIONAL RANGES OF 18 SPEEDS		
RANGE 1.		20 TO 1000 r.p.m.
RANGE 2.		28 TO 1250 r.p.m.
RANGE 3.		32 TO 1600 r.p.m.
TABLE FEEDS: up to 63 ins./min.		
FOUR OPTIONAL RANGES OF 16 FEEDS		
RANGE 1.		0·8 TO 25 ins./min.
RANGE 2.		1·18 TO 37·5 ins./min.
RANGE 3.		1·6 TO 50 ins./min.
RANGE 4.		2 TO 63 ins/min.
TABLE RAPID TRAVERSE		160 ins./min.

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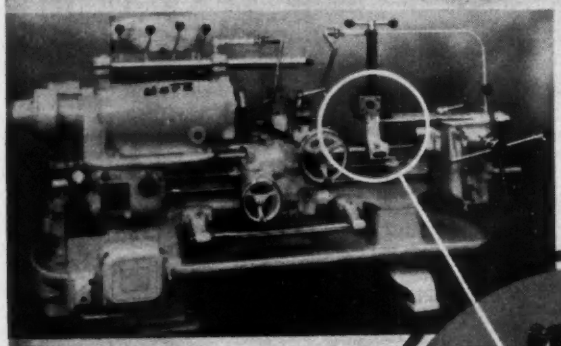

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and
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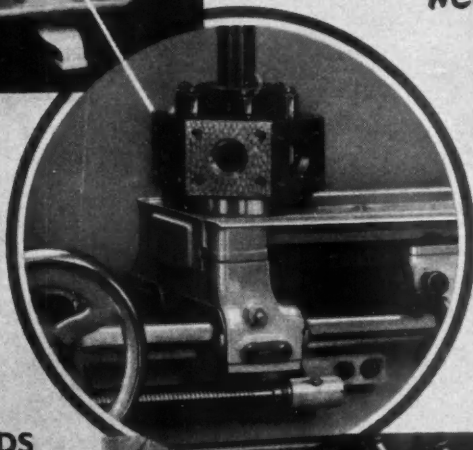

Throughout the whole of its forward movement, the hexagonal turret is supported underneath by a sliding bridge which is in direct contact with the bed on all its working surfaces. This ensures correct alignment at all times, whatever weight of tools the turret carries.

The New DOUBLE-SLIDE allows heavier work with higher rates of metal removal

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	2DS	3DS	7DS
Bar Capacity with Standard Spindle	1¼in	1½in	2in
with oversize Spindle	1½in	2in	2½in

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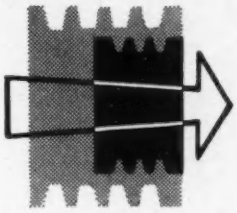

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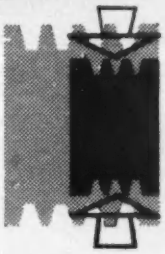

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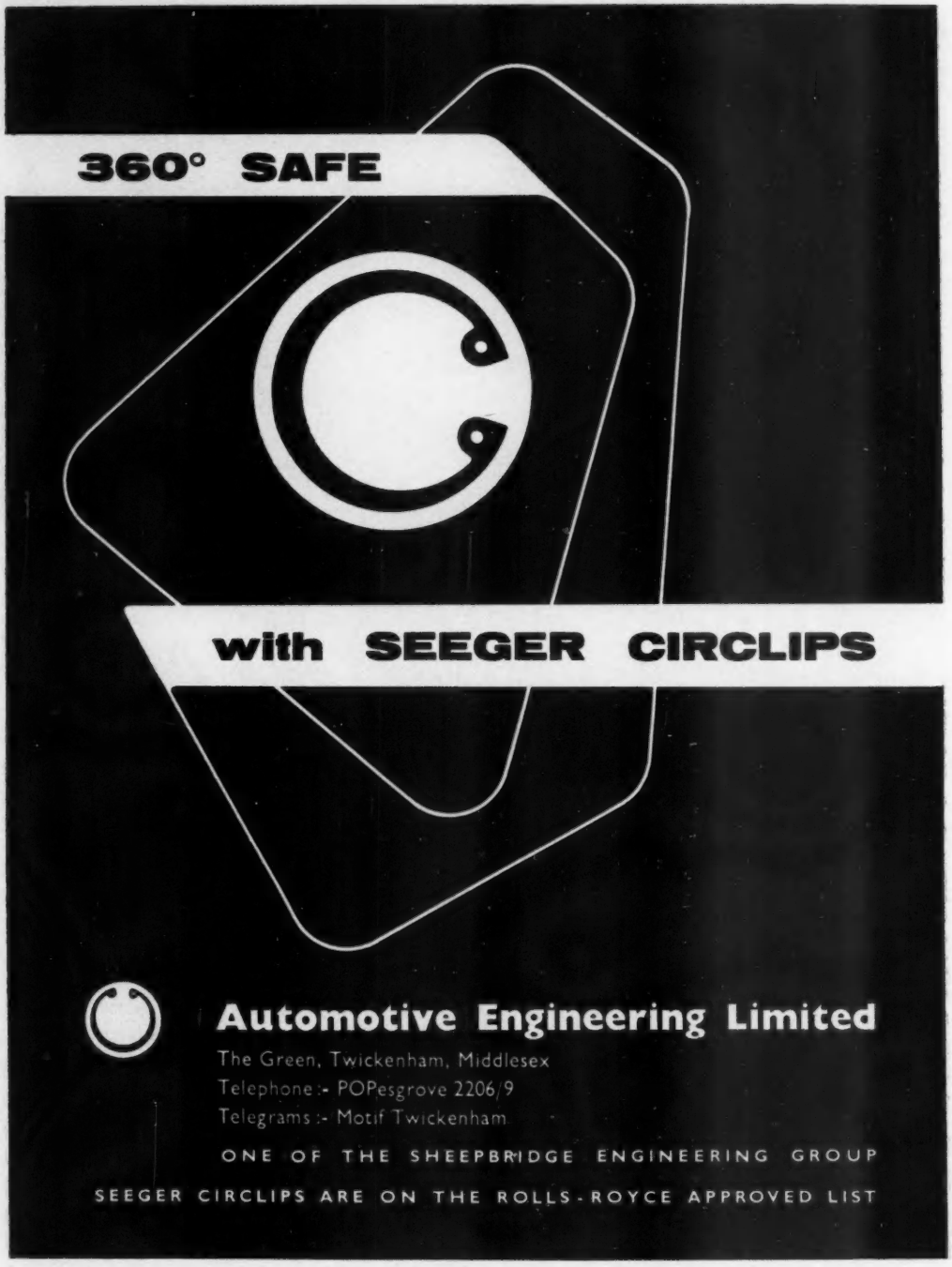
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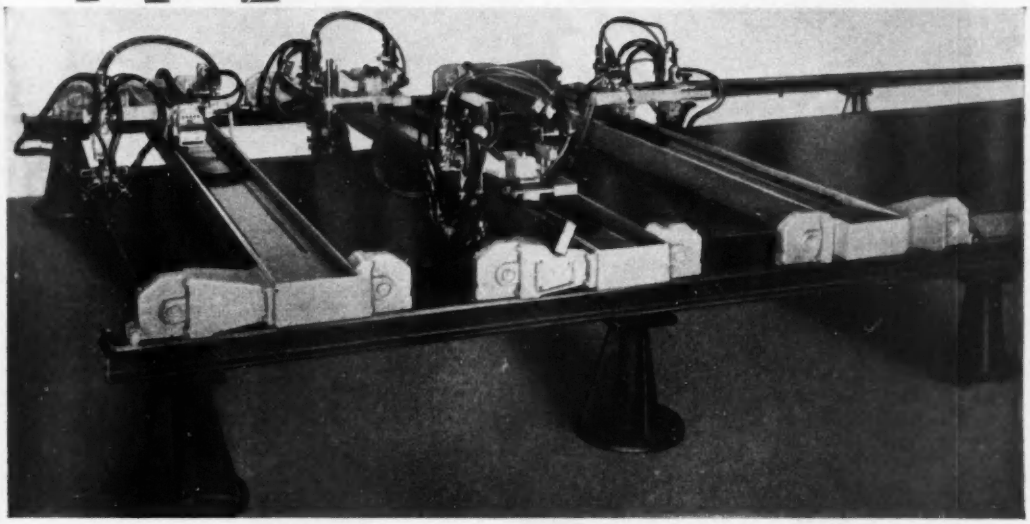

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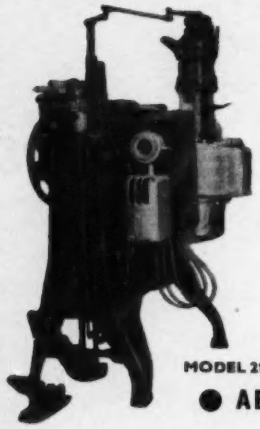
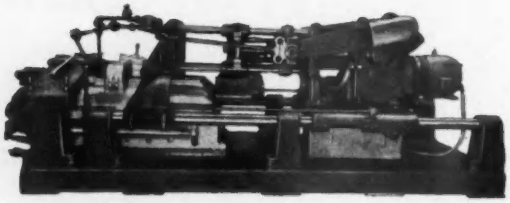
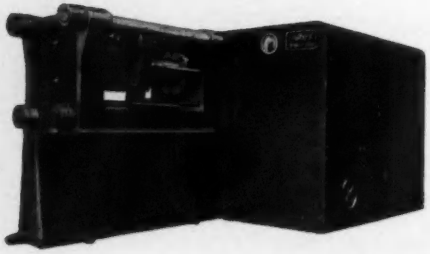


MODEL 215E



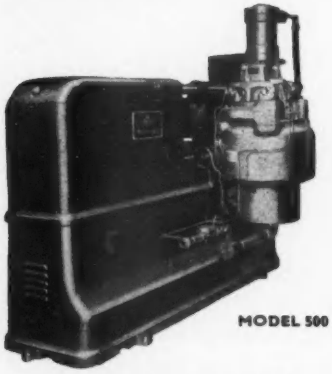
MODEL 4

● ABSOLUTE ACCURACY



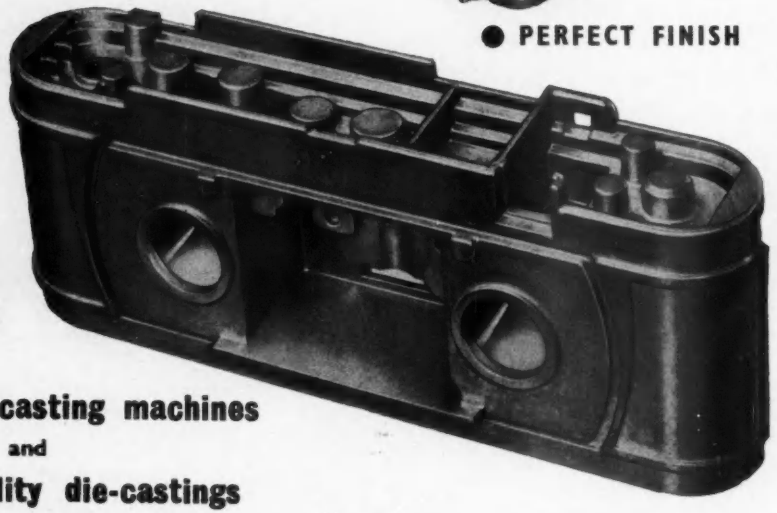
MODEL 450

● STRENGTH



MODEL 500

● PERFECT FINISH



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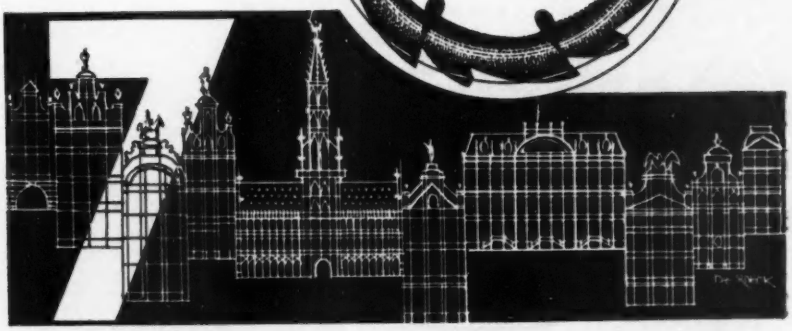

Intending visitors are strongly recommended to make hotel reservations as soon as possible. The appointed agents are Thos. Cook & Son Ltd.

Copies of the official exhibition catalogue will be available in early August. Applications should be forwarded now to the Commissariat General de la 7eme Exposition Europeenne de la Machine-Outil, 13, Rue des Drapiers, Brussels, 5. At the same time a transfer of Belgian Frs. 100 to the General Commissariat's Account No. A.26/1617 at Banque de Bruxelles, Brussels should be arranged and confirmed to the Commissariat with your order.

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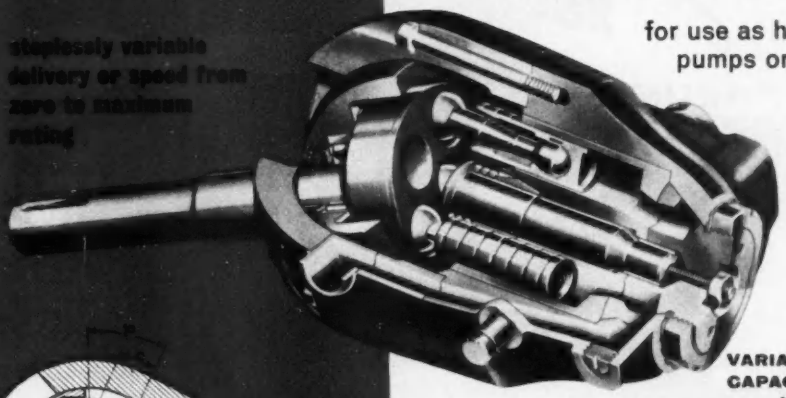
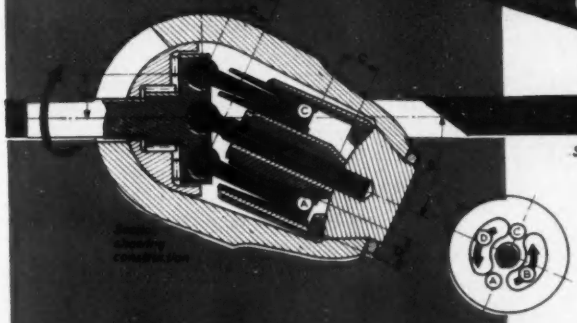


VARIABLE CAPACITY UNIT



The working parts of the unit are contained in a steel body. This body can be moved through an angle relative to the shaft. Such a movement changes the stroke of the pistons and in consequence the output of the unit, if it is used as a pump, or the speed of the shaft if it is used as a motor. Variable units are completely reversible as regards oil flow or shaft direction. Moreover the units themselves can operate in any position.

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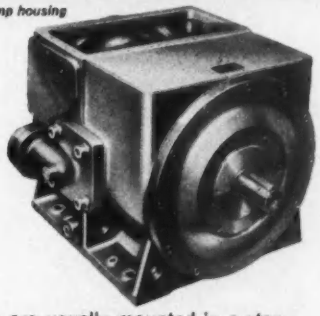

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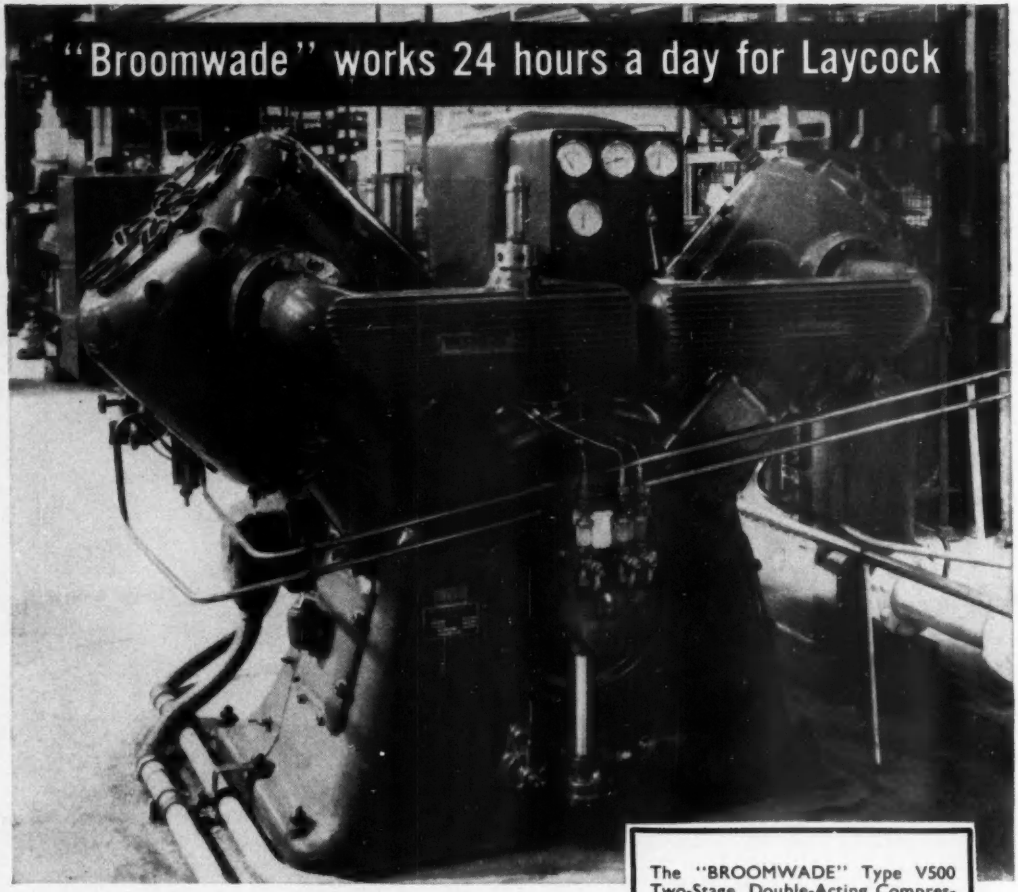

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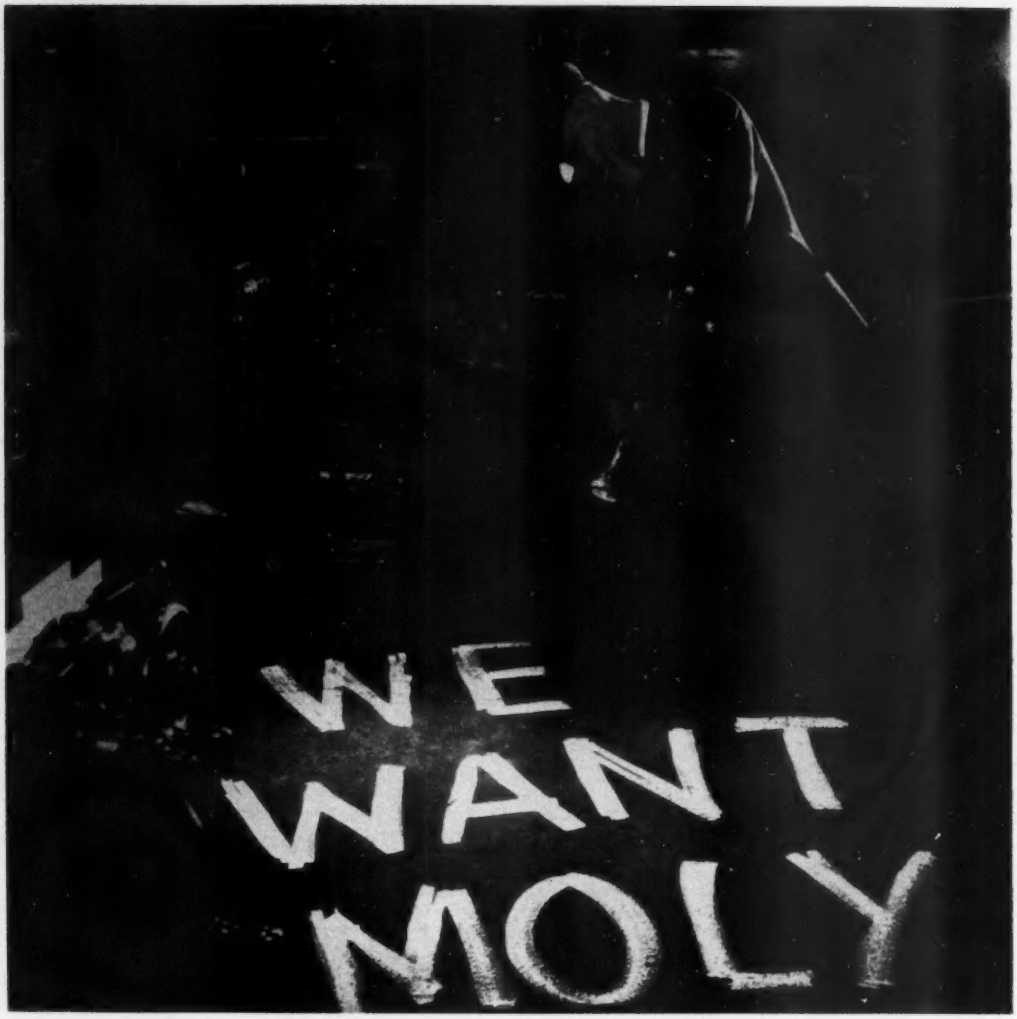

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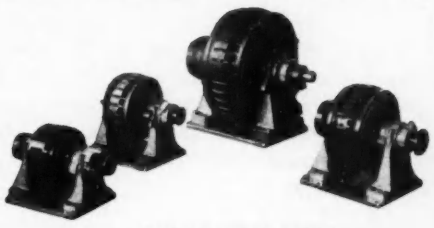

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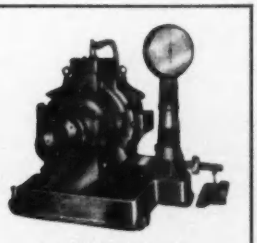

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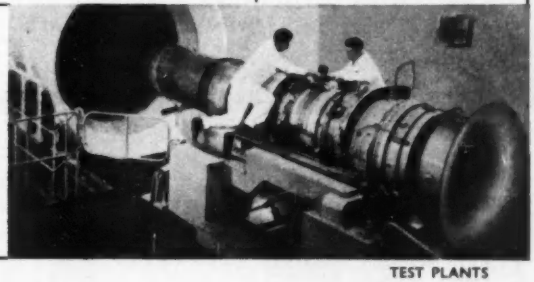

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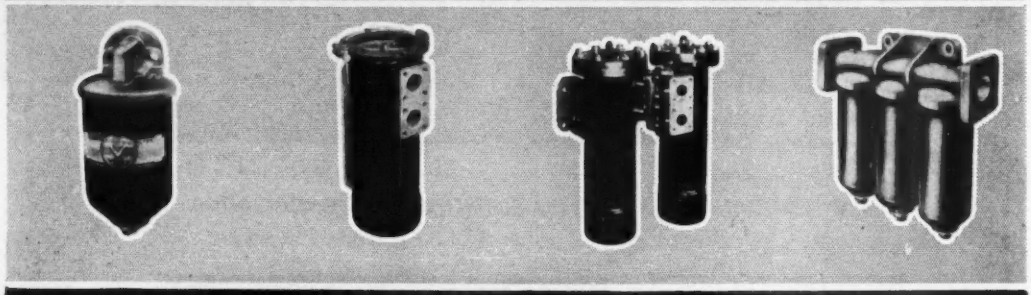

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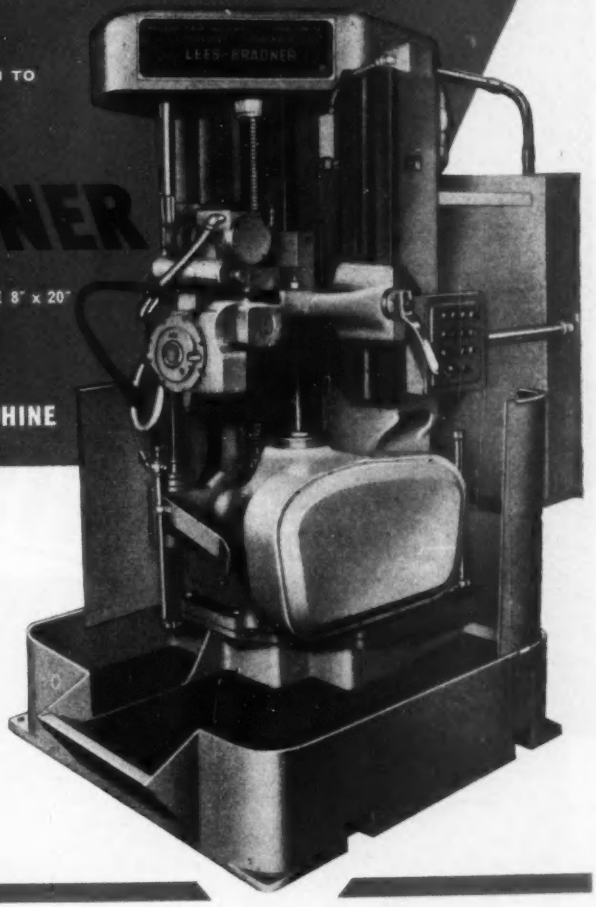

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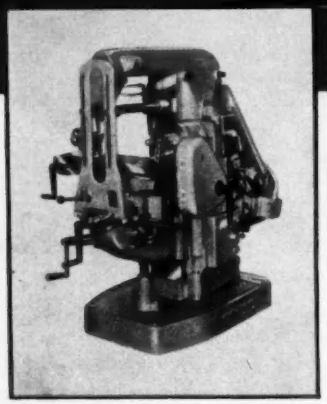

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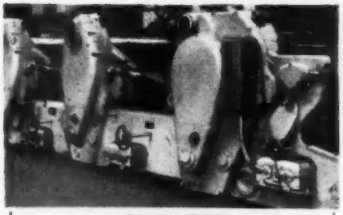
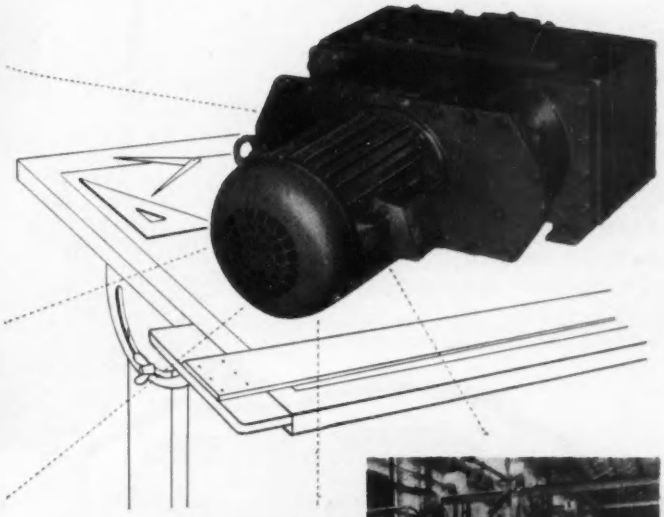
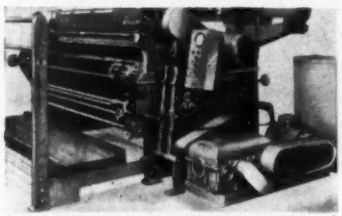


BAKERY OVEN
Courtesy T. & T. Vicars Ltd.





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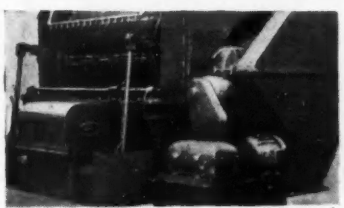
Courtesy William Whitely & Sons Ltd.



FILTER
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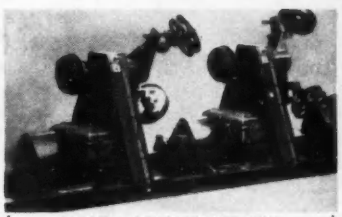

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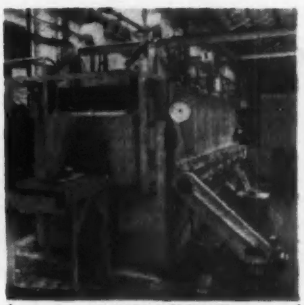

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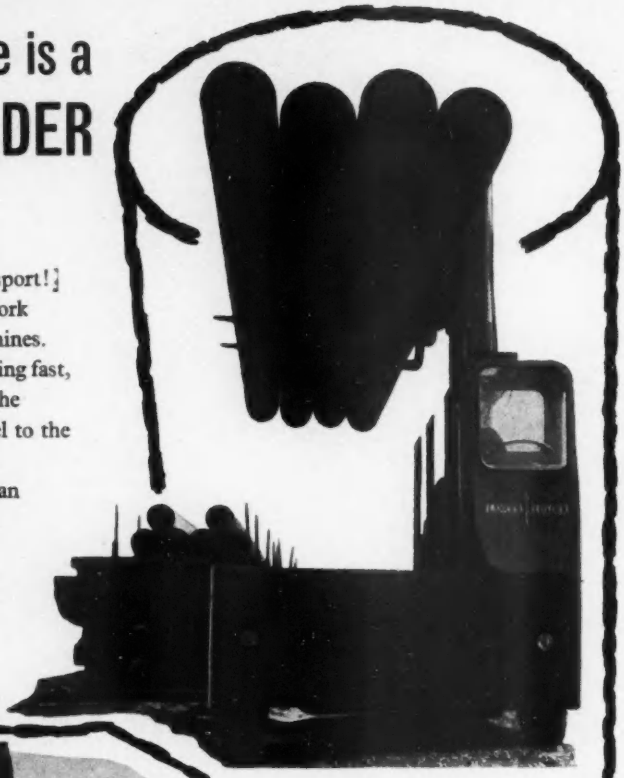

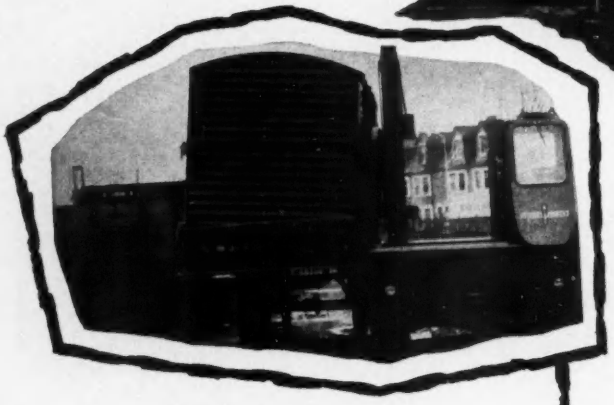

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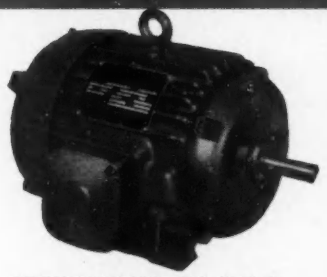

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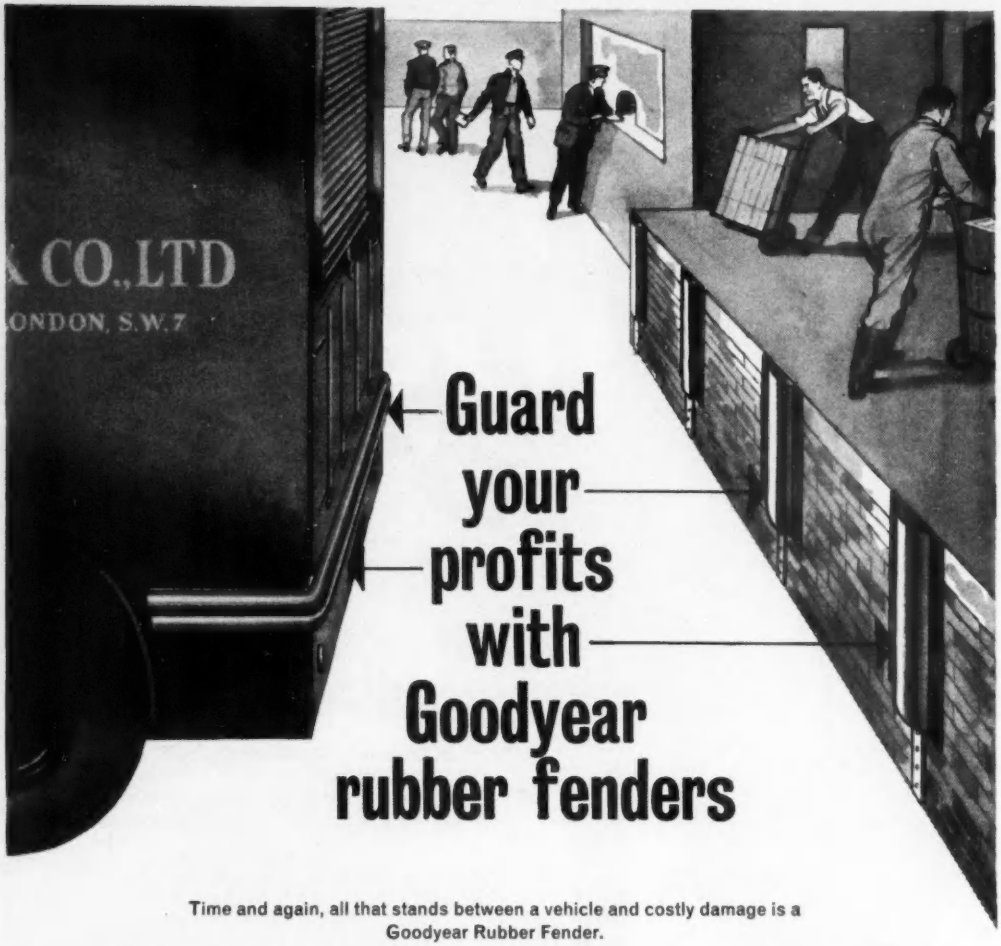

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THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *BERYLLIA HEAT SINKS FOR TRANSISTORS*

Materials having low electrical conductivity and high thermal conductivity have long been sought for use in equipment where higher power levels and more compact designs aggravate the problem of heat dissipation, transistor users being among those most concerned. While effective transistor heat-sink devices have been made using, for instance, thin sheets of mica or of anodized aluminium, these materials have certain disadvantages. Thus, thin sheets of mica are fragile, while anodized coatings, on aluminium can be penetrated or scratched by burrs or metal chips.

It has now been found that beryllia has properties which make it an excellent transistor heat-sink material, as it has a thermal conductivity equal to that of aluminium, its dielectric loss is the lowest of any commercially available ceramic, and it is dielectrically stable up to 400°C and 10,000 Mcs. Furthermore, beryllia has high strength and shock resistance, good dimensional stability, and an extremely low moisture absorption, and it cannot be caused to malfunction by scratches or other abrasions. It is known that such substances as grease between the transistor base, insulator, and heat sink greatly improve heat transfer, and that silicone-based compounds are commonly used for this purpose. However, the conductivity of these compounds does not approach that of beryllia, so that consideration should be given to preparing a silicone fluid filled with beryllia powder. Such a mixture should have a higher conductivity than present silicon greases and would therefore be more attractive to transistor users.

From *Electronics*, U.S.A., May 5, 1961, pp. 76–78.

● *IMPROVED IGNITION SYSTEM FOR PETROL ENGINES*

Ignition systems for internal combustion engines have been proposed in which adjustment of the ignition is effected by means of an electronic regulator incorporating a relaxation oscillator operated by a mechanical switch coupled to the crankshaft of the engine. Unfortunately, however, arrangements of this type necessitate a high degree of stability of the circuit components used in the relaxation oscillator, especially with respect to ageing and temperature effects, which have a direct influence on the accuracy of ignition timing. For this reason, an improved ignition system has now been developed and has the additional advantage that fewer transistors than those required by previous systems of the same type can be used.

In the new system, current is supplied by an a.c. generator with a permanent-magnet armature coupled to the drive shaft of the ignition system and fitted at its periphery with the same number of pole pairs as the number of engine cylinders. A power transistor is arranged with its output circuit in series with the primary circuit of an ignition coil, the ignition spark being produced by blocking the transistor. A monostable relaxation oscillator incorporating an input transistor, an output transistor, and a time-member (comprising a condenser in parallel with two resistors) is connected to the input of the power transistor. In this way, the power transistor becomes conductive when the relaxation oscillator is in its stable condition. A frequency-dependent phase shifter is connected to the output of the a.c. generator and to the relaxation oscillator, delivering a control voltage which leads the voltage delivered by the generator by an angle that increases with increasing engine speed. The relaxation oscillator is controlled out of its inoperative stable condition into its operative unstable condition when the control voltage delivered by the phase shifter has a predetermined polarity and exceeds a predetermined value, blocking the power transistor and producing an ignition spark. After a relaxation period determined by the time-member, the oscillator returns to its stable condition and, at the same time, causes the power transistor to become conductive, ready for the next ignition surge.

From *Brit. Pat. Spec.* 861,534, Robert Bosch, G.m.b.H., Stuttgart-W, Germany.

● *ELECTROMAGNETIC METAL FORMING*

In electromagnetic metal forming, the magnetic flux lines exert sufficient pressure on conductive material to exceed the elastic limit of the metal, thus causing permanent deformation. In this process, conductive metal parts are introduced into a coil in such a manner that they are flux-linked with the work coil and can be considered as short-circuited secondary single-turn coils. This means that the primary

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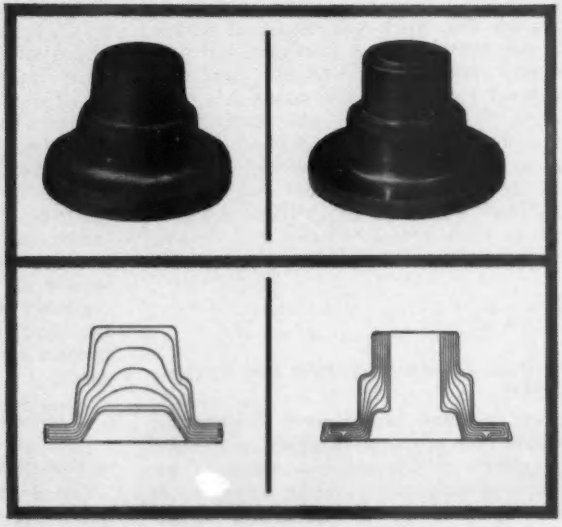
Forgings and Presswork Ltd are now equipped to produce a wide range of cold extruded steel parts and would welcome the opportunity to apply their specialized knowledge to *your* products.

The Motor Car Propeller Shaft Flange shown (left), was formerly made from Heat Treated EN8 steel. It is now produced from low carbon steel whose properties after extrusion (right) are equal to those of the EN8.

The pattern of flow lines in the extrusion (right) follows the external contour closely and is superior even to that of a forging where generous machining allowances are usual and really deep piercing is impossible.



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work-coil current will be a maximum, owing to the short-circuited secondary. Consequently, when electrical energy is applied to the work coil, a net resultant magnetizing force is applied to the workpiece and, when this energy exceeds the elastic limit of the workpiece material, permanent deformation takes place. To achieve this effect, energy must first be boosted to a high level, and this energy must then be applied to the workpiece in a specific fashion.

The energy level is raised by using a capacitor bank, and the stored electrical energy is then discharged through expendable or permanent coils. The charging voltage, which may be as high as 30 kV, is supplied to the capacitors from a high-voltage power supply, the energy stored in the capacitor bank varying directly with the value of the capacitance and as the square of the applied voltage. Thus, energy levels can be increased by adding capacitors to the bank or by increasing the charge voltage. Capital equipment costs limit the number of capacitors, while the upper limit on voltage—about 10kV—is imposed by the breakdown point of the insulating materials. A high-voltage switching circuit incorporating ignitron tubes is used to discharge the stored energy.

Rods and tubes have been swaged by this process, and investigations have been made with respect to the blanking, forming, embossing, and drawing of metals. At present, electromagnetic forming is limited to small parts, usually with a blank size of 12 in. in diameter or less and a thickness of $\frac{1}{8}$ in. Further investigations into energy storage and release will undoubtedly improve this process, which, even to-day, is suitable for preforming tasks at a quality level difficult to exceed, or even impossible to achieve, by other methods.

From *The Tool and Manufacturing Engineer*, U.S.A., May 1961, pp. 105–108.

● *ECONOMICAL METHOD OF COATING PIPES INTERNALLY WITH PLASTICS*

An economical new method for coating the inside of metal pipe with a wide variety of thermoplastics is claimed to have a broader area of potential use than any other plastic pipe-lining method, particularly in chemical process equipment. The process is extremely versatile, since coatings can be deposited in thicknesses from 0·001 in. to 0·060 in., depending on the gauge and type of metal treated, the type of plastic deposited, and the time and temperature of treatment. The size of pipe that can be coated is determined mainly by the size of the processing equipment.

Because of proprietary reasons and pending patents, only a limited amount of information on this process is at present available. However, it may be stated that cleaning and surface preparation of the pipe in a conventional chemical bath are followed by heating in a conveyor oven, with the pipe in a vertical position. When the pipe has reached the end of the oven, it is clamped in a coating apparatus, where the resin, introduced in powder form, is fused to the metal at a temperature of 400°F. The coatings are applied within 6 or 7 seconds—a considerably shorter period than that required for other pipe-coating and lining processes.

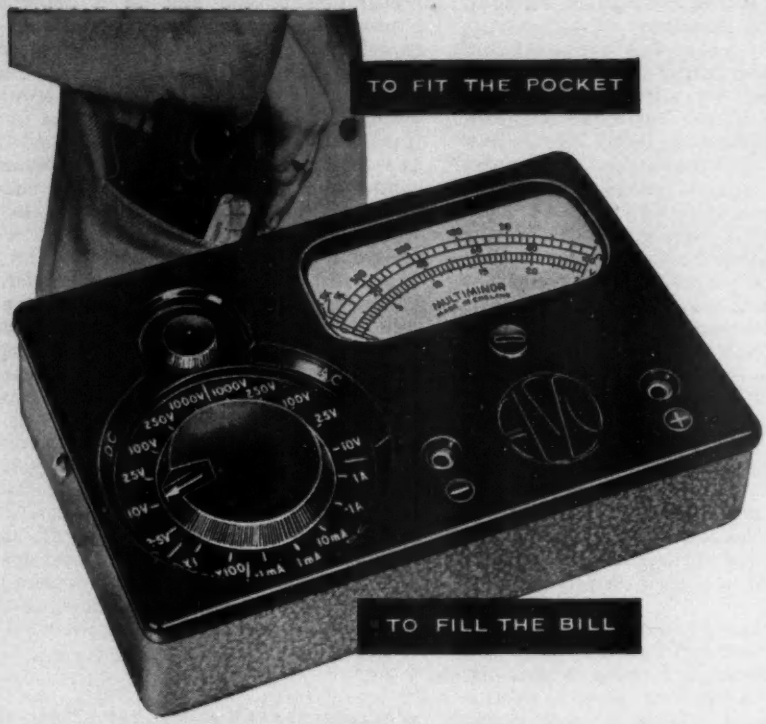
The coatings are extremely uniform, and thickness variations can be held to less than 5% in any length of pipe, while circumferential thickness variations are negligible. Because of their extreme smoothness, they lower frictional resistance and reduce the power required for pumps, particularly where piping systems are complex. The coatings, which possess excellent adhesion and bond strength, have so far been applied primarily to carbon steel and aluminium, but they can also be applied to copper and copper-alloy pipes and other corrosion-resistant alloys, if a particularly high corrosion resistance is needed. Almost any thermoplastic can be applied by the new process, but most development work has been conducted with chlorinated polyether, because this material ideally combines high chemical resistance with relatively low cost.

From *Materials in Design Engineering*, U.S.A., April 1961, pp. 10–11.

● *PULSED SYSTEM FOR X-RAY CINEMATOGRAPHY*

A new pulsed X-ray system which makes it possible to make cine-radiographs of high-speed phenomena in one microsecond or less, is expected to find widespread application in shock and vibration studies, radiation effects, rocketry, medical radiology, ballistics, and crystallography. The system includes an oxide-coated thermionic hot-cathode X-ray tube, capable of conducting high currents at high voltages with fast rise-time characteristics. With a life in excess of over a million shots, the tube has excellent reproducibility of pulse length, voltage, current, and consequently X-ray output characteristics.

The pulsed system consists of two compact units, i.e., an X-ray console with the X-ray generating tube, power supply, and control circuits, and an image-intensifier console. The X-ray tube is pulsed with a square-wave voltage of one microsecond duration. The rate of application is continuously variable from 1 to 30 pulses per second, amplitude of the square-wave voltage applied to the tube being continuously variable from 0 to 150 kV. When the tube is operated at 150 kV with a beam current of 130 A, the X-rays are generated by an electron beam of approximately 20 MW focused on the X-ray conversion target. The resulting high-intensity



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0— 250 V.	
0— 1000 V.	

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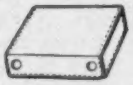

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From *Nondestructive Testing*, U.S.A., March–April, 1961, p. 93.

● ***IMPROVED METHOD OF SILICONIZING METAL COMPONENTS***

A number of disadvantages are inherent in conventional methods of siliconizing metal components, including the use of high siliconizing temperatures which, in the case of molybdenum, can give rise to an unfavourable reduction in mechanical properties and irregularities in the siliconized layer produced. To overcome these drawbacks, a recently patented method of siliconizing basically comprises exposing metal parts, especially those made of molybdenum, tungsten, tantalum, niobium, and their alloys, to the action of a molten silicon-containing copper alloy at between 800 and 1200°C. The copper is capable of dissolving silicon, but does not itself react (or only to a small extent) with the metal to be siliconized.

The silicon content of the copper alloy should be between 3 and 30%, but a content of from 10 to 15% is considered specially advantageous. If desired, up to 50% of the copper content of the alloy can be replaced by one or more metals, such as silver, tin, zinc, lead, aluminium, cadmium, or gold, mainly for the purpose of reducing the melting point of the alloy. Also, up to 20% of the silicon content can be replaced by boron, to incorporate a small amount of boron in the siliconized layer and hence to improve its quality with respect to oxidation resistance and to sudden changes in temperature. The recommended method of producing the siliconized layer is by dipping the components into the molten alloy, but the layer can also be produced by spraying, evaporation and condensation, or in powder form, with a subsequent heat treatment to melt the alloy and form the siliconized layer.

After the siliconized component has been removed from the melt and allowed to cool, any adhering silicon-containing copper alloy is removed by chemical or electro-chemical pickling, leaving a uniform and firmly adherent siliconized layer on the surface of the metal. For example, when molybdenum components are dipped into the molten alloy, the dissolved silicon converts the surface to molybdenum silicide. Subsequent treatment with dilute nitric acid then removes any mechanically adhering copper, as well as the silicon dissolved in the copper and not used in building up the layer of molybdenum silicide, which is unaffected by the treatment.

From *Brit. Pat. Spec.* 865,670, Metallwerk Plansee A.G., Reutte, Tyrol, Austria.

● ***METHOD OF COATING SURFACES BY ELECTRODEPOSITION***

Stated to provide a means of coating surfaces with greater uniformity than is possible with conventional methods, such as brushes and spray guns (electrostatically assisted or otherwise), a new electrodeposition coating process also has the advantage that a greater variety of materials can be coated and that the treatment can be arranged in such a way that effective control can be exerted over the thickness and uniformity of deposition by controlling its time and rate. The materials used for coating can include all particles, resins, waxes, dyes, gums, and pigments that can be dispersed in a liquid of suitably high volume resistivity, while the items to be coated can be of any shape, can be made in any suitable form, e.g., film, sheet, or plate, and can be conducting, semi-conducting, or non-conducting.

The process essentially comprises placing the material to be coated in an insulating bath between two or more electrodes, which serve to deposit the coating material onto the surface, with or without relative movement between the material and electrodes. For this purpose, the coating particles are dispersed in an electrically insulating liquid which also acts as a suspension agent, and an electrostatic field is established in the liquid to move the coating material to the backing material, which has previously been coated with a control agent for holding the deposited material on the backing. The electrodes are immersed in the liquid at an appropriate distance from each other, depending on the voltage subsequently applied between them (normally from 500 to 15,000 V), but sufficiently great to ensure that arcing cannot occur. When the field is applied between the electrodes,

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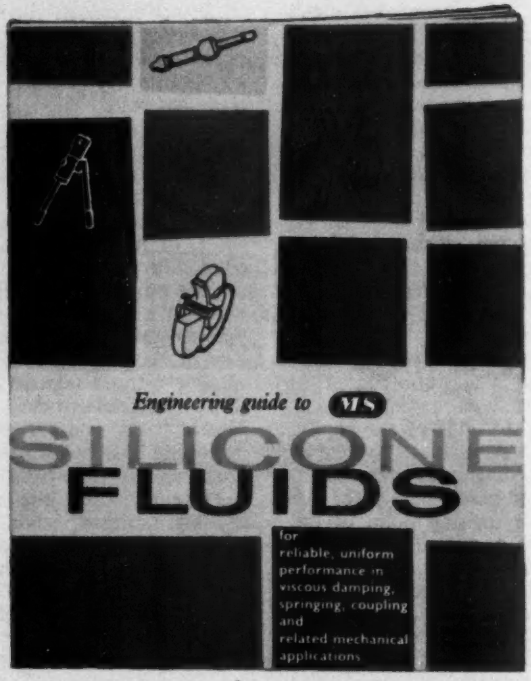

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particles are rejected by one electrode, travel through the liquid, and are then deposited on the material to be coated, which is connected to the other electrode, a substantial coating being achieved in this way very quickly, e.g., 2 sec.

Typical applications of the process include its use for enamelling or painting sheet materials and finished components, such as car bodies, for coating abrasives onto paper or other backings, for welding plastics, for making fluorescent screens for X-ray and other work, for coating carbon paper, for applying anti-corrosive coatings, and for producing tape for tape-recorders. A typical formulation for a recording-tape coating material contains 100 parts by weight of an acetal resin as the control agent, 120 parts of iron oxide as the recording medium, 0·5 parts of cobalt napthenate and 0·5 parts of manganese naphthenate as driers, and 40 parts of toluene. These materials are milled together in a ball mill for 8 hr and are then dispersed in toluene containing 10% by volume of carbon tetrachloride.

From *Brit. Pat. Spec.* 866,780, The Commonwealth of Australia, Melbourne.

● *PROBLEMS OF HIGH-SPEED PHOTO-MICROGRAPHY IN RESEARCH*

In many investigations, still photography and cinematography play an important part in determining how certain faults occur or whether equipment is functioning properly, and in these investigations the need for sufficiently short exposures to avoid blurring of moving objects is often a serious problem. The problem is greatly aggravated in the case of photomicrography, where the relative speed of the image of a moving object is a function of the degree of magnification used.

When extremely rapid phenomena are being investigated, such as detonation, deflagration of solid and liquid propellants, atomization, the formation of electric sparks, the "explosion" of thin wires by high current surges, the formation of shock waves, the fracture of brittle materials, and the vibration and fatigue of metals, the rates of movement are much higher and the significant detail can be very small. In such cases, the use of specialized cameras is essential. Of the types of cameras used for taking sequences of pictures through a microscope, all of which can give a resolution of from 200 to 300 lines across the frame in each dimension, the best known is the rotating-prism camera. Some of these cameras can take very long sequences of pictures at a rate of 10,000 pictures per second with normal frame height or twice this speed with half-height frames. Image-dissection micrographs can record a sequence of about 300 frames at 100,000 frames per second, while some rotating-mirror framing cameras can take a sequence of 25 frames at a rate of a little over 1,000,000 per second.

As pointed out in a recent note, it would obviously be of great advantage in many fields of research if more frames and higher rates, coupled with better resolution, could be obtained. At present, the factors to be considered in making a choice among the various types of equipment available underline a general problem in high-speed photography and, despite many recent advances, it is still not possible to combine in a single camera an instrument capable of working at high magnifications with wide-aperture lenses, very high operating speeds, extremely brief exposures, and high resolution. It is therefore emphasised that there is a definite need for continued research and development in the entire field of high-speed photography.

From *Materials Research & Standards (ASTM)*, U.S.A., May 1961, p. 406.

● *MAGNETIC DEVICE FOR THE HIGH-SPEED SENSING OF SMALL CURRENTS*

A magnetic device, capable of sensing small currents, has been developed, its core being formed by a bar or stick of a low-coercive-force square-loop ferrite. Two holes pierce the stick, transverse to its long axis, and the current to be detected flows in a solenoid surrounding the stick. The sensing of this current is accomplished by observing the flux switched around the holes under the action of a pulse of current flowing through them. The material around the holes behaves like a pair of torodial cores, whose switchable flux can be controlled by the solenoid current. This flux can be made to be independent of solenoid currents below a certain limit.

A theory which explains the observed behaviour is developed in a recent paper, in which equations are derived to give the dependence of the output on the magnetic field generated by the solenoid in terms of the saturation induction and coercive force of the ferrite and of the core dimensions. Typical experimental data are included and are compared with the predictions of the theory. In some systems it is necessary to monitor the status of a large number of slowly varying inputs by high-speed scanning. A device, called a "ferrod", has been developed for this purpose. Fundamentally a magnetic amplifier, the ferrod makes use of two interacting flux configurations, one of these having high remanence, and the other low remanence. The latter controls the former, while the reverse interaction is small. The fact that the control winding is on a bobbin rather than a toroid makes it economically attractive for many applications.

From *Communication and Electronics, AIEE*, U.S.A., March 1961, pp. 1–3.

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A World Review of DESIGN & PRODUCTION — RESEARCH & DEVELOPMENT

VOL. XXII No. 6 JUNE, 1961

Constant-Force Spring Systems

By E. E. UNGAR and K. S. PEARSONS

From *Product Engineering*, U.S.A., Vol. 32, No. 13, March 27, 1961, pp. 54–59, 16 illustrations.

A SPRING system which provides a nearly constant restoring force for a reasonably large portion of its deflection is particularly suitable for absorbing shock and vibration. The reasons why such systems are superior to conventional spring systems with linear or almost-linear force-deflection characteristics can be summarized as follows:—

(1) A constant-force spring system absorbs a given amount of energy with a lower maximum force for a given deflection.

(2) If the maximum shock intensity (or package-drop height) specified in design is exceeded, e.g., when shock energy turns out to be higher than anticipated, the increase in force will not be excessive.

(3) Severe amplitudes at resonance, such as occur in linear systems, are avoided, because the resonance frequency for a constant-force system varies with amplitude. As soon as amplitudes build up, the system is therefore no longer operating at resonance.

Two types of spring system can be employed to produce constant-force characteristics, i.e., buckled-lever systems, in which a spring is compressed or tensioned between jointed levers buckling under load, and columnar systems, which are composed of a material cut or moulded to buckle under load.

Although constant-force spring systems have primarily been developed to improve the housing of instruments and components in aircraft and spacecraft, there is no reason why they should not find wide use in vibration and shock mounts for industrial machinery.

Buckled-Lever Systems

As mentioned above, levers which "buckle" under load can be combined with linear springs (Fig. 1a and Fig. 1b), to provide constant-force characteristics over part of the deflection, as shown in Fig. 2. An external load P applied vertically is counteracted by two linear springs, i.e., a tension spring with stiffness k_1 which acts through a linkage, and a compression spring of stiffness k_2 which acts directly. The linkage reduces the effectiveness of the tension spring in counteracting P as the spring deflection increases.

If the compression spring were removed from the system, the force-deflection characteristics of the system would be

$$\frac{P}{k_2 L} = \left(1 - \frac{D}{\sqrt{D^2 + \frac{2y}{L}\sqrt{1-D^2} - \left(\frac{y}{L}\right)^2}}\right) \times \left(\sqrt{1-D^2} - \frac{y}{L}\right) \quad .. \quad .. \quad .. \quad (1)$$

where $D = (b - a)/L$, k_1 = spring rate [lb/in.], P = load [lb], a = frame length [in.], b = free length of tension spring [in.], and y = deflection of the system measured from its initial free height h_0 [in.].

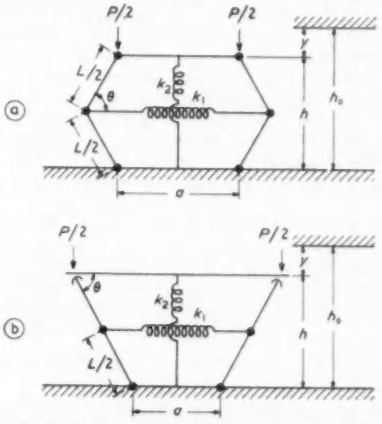


Fig. 1. Buckled-lever systems with compression and tension springs.

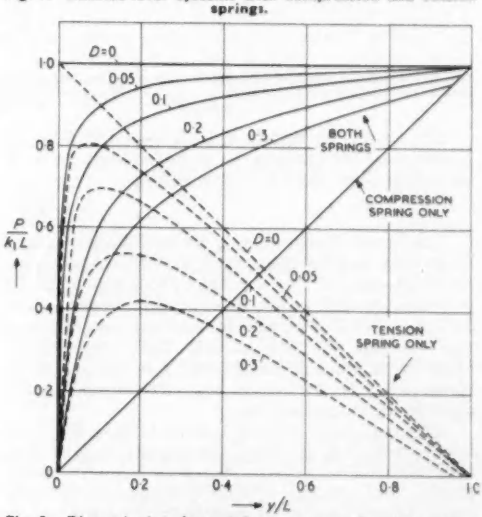
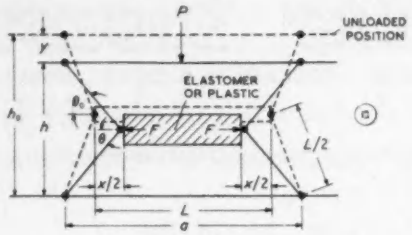


Fig. 2. Dimensionless force-deflection curves for the systems shown in Fig. 1.



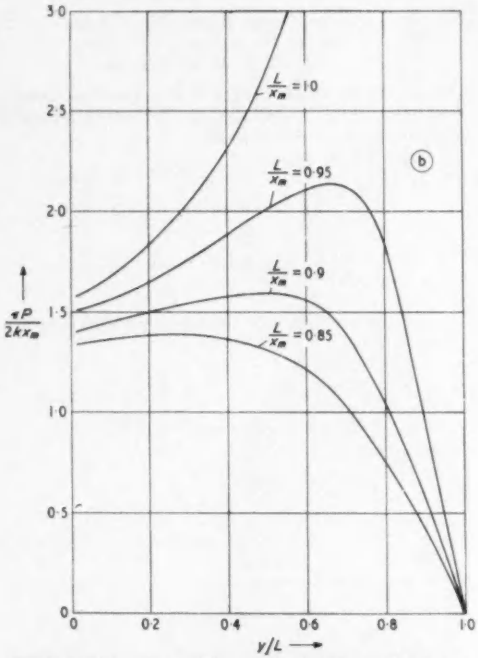


Fig. 3. Configuration and force-deflection characteristics of a system consisting of buckled levers in combination with a resilient material.

If, in turn, the tension spring is removed from the system, only the compression spring opposes the load, according to the force-deflection relation

$$P = k_2 y \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

The force-deflection relation for the linkage with both springs can then be obtained by adding the loads given by eqs. (1) and (2). Fig. 2 is a plot of eqs. (1) and (2) for various values of D on the basis of equal spring rates, i.e., $k_1 = k_2$. The full curves represent the summation of eqs. (1) and (2) and indicate that constant-force behaviour is closely approximated if D is small, i.e., if the spring acting on the linkage has a free length b nearly equal to the linkage spacing a.

Although many springs behave linearly for quite large deflections (e.g., helical steel springs), most resilient materials tend to become stiffer with increasing strain. Rubbers and plastics, in either homogeneous or foam forms, behave linearly for small deflections, but usually develop very large forces at large strains. The force-deflection characteristics for such materials can be approximated as

$$F = \frac{2K x_m}{\pi} \tan\left(\frac{\pi x}{2x_m}\right) \qquad \ldots \quad \ldots \quad (3)$$

where K is the initial slope of the force-deflection curve and is equal to the spring rate of the material under small deflections, and x_m is the value of deflection x for very large values of F.

For uniform materials, F can be interpreted as stress and x as strain. However, the "tangent" behaviour of eq. (3) may also occur for non-uniform, such as beer-barrel-shaped, samples, so that the force-deflection interpretation is more generally useful.

Because a sample with this "tangent" elasticity has a climbing force-deflection rate, and the buckled-lever linkage with only a compression spring has an inherent "unstiffening" characteristic, the two can be combined as in Fig. 3a to give a relatively flat force-deflection relation. Although this figure shows the tangent-elastic material in compression and the levers buckled inwards, a nearly identical analysis may also be applied for materials in tension, with the levers buckled outwards.

The force-deflection relation for such an assembly is

$$P = \frac{2K x_m}{\pi} \frac{\sin\theta_0 - y/L}{\cos\theta_0 + x/L} \tan\left(\frac{\pi x}{2x_m}\right) \qquad \ldots \quad (4)$$

where

$$\frac{x}{L} = -\cos\theta_0 + \sqrt{\cos^2\theta_0 - (y/L)^2 + 2\,(y/L)\sin\theta_0}.$$

Configurations with $\theta_0 \simeq 90°$ are likely to produce the most useful results. For $\cos\theta_0 = 0$, $\sin\theta_0 = 1$, eq. (4) reduces to

$$P = \frac{2Kx_m\left(1 - \frac{y}{L}\right)}{\pi\sqrt{\frac{y}{L}\left(2 - \frac{y}{L}\right)}} \tan\left(\frac{\pi L}{2x_m}\sqrt{\frac{y}{L}\left(2 - \frac{y}{L}\right)}\right) \quad (5)$$

Curves of eq. (5) for several values of L/x_m are shown in Fig. 3b, from which it will be noted that a reasonably wide and nearly flat range can be obtained for values of L/x_m between about 0·85 and 0·9.

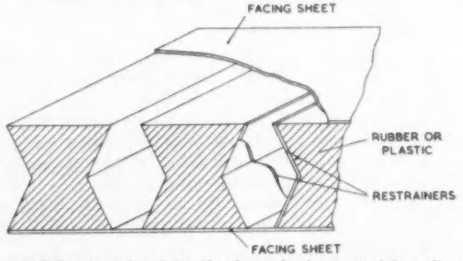


Fig. 4. Constructional details of a packaging material or vibration mount employing the buckled-lever principle.

Many practical configurations embodying the buckled-lever principle are possible. A typical system, using a resilient material such as rubber or plastic foam, is illustrated in Fig. 4. The prismoids of the material have restrainers on the sides and facing sheets on the tops and bottoms. The restrainer may be made of any relatively rigid material, such as sheet plastic. Hinging action is provided by slits or notches in the sheets or by inclusion of actual hinges in the form of flexible fabric.

A force applied to the facing sheets compresses the

assembly vertically. Simultaneously, it compresses the resilient material directly in the vertical direction, because of the facing sheets, and in the horizontal direction because of the restrainers. The vertical compression has the same effect as the compression spring in Fig. 1, while the horizontal compression has the same effect as the tension spring.

The results of static force-deflection measurements on such a configuration are given in Fig. 5, where deflection is expressed as a percentage of the free height. Curves for the rubber filler material (acting as a solid without restrainers) are also included. The buckled-lever system can absorb a considerably greater amount of energy for a given amount of deflection than can the plain sponge rubber. Inclusion of the restrainers changes the force-deflection curve to one that approaches the constant-force material more closely.

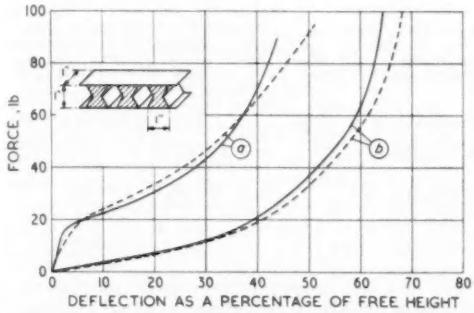


Fig. 5. Force-deflection characteristics of a buckled-lever system employing open-cell sponge rubber (full curves) and closed-cell sponge rubber (dotted curves). Curves *a* refer to a system with restrainers and curves *b* to a system without restrainers.

The deviation of force-deflection curves from the desired horizontal is to some extent caused by the fact that, during these tests, some of the filler material was subjected to large strains, and that the material stiffens considerably under such strains. Various modifications were therefore tested, involving the removal of some portions of the filler material in regions where high strains are likely to occur. Results with some such modifications indicate that curves with wider and more nearly flat portions can indeed be obtained.

Flatter curves can be obtained from buckled-lever configurations using a polyurethane foam filler. Although even the plain foam exhibits a reasonably wide flat region, adding the restrainers increases the energy-absorption capabilities of the foam considerably for a given deflection and simultaneously widens the plateau region and increases the initial slope.

Configurations using a resilient material in compression produce nearly flat force-deflection characteristics with, however, some constructional difficulties. The resilient material buckles in compression unless a reasonable thickness is used. However, the greater the thickness, the sooner the facing sheets make contact with the material, and the smaller is the range of available deflections over which a nearly constant-force behaviour is obtained. Employing the material in tension overcomes this buckling difficulty, but brings problems of fastening it to the restrainers.

The most promising configuration with tangent-elastic properties is a two-way directional buckled-lever system, i.e., two two-lever systems at right-angles to each

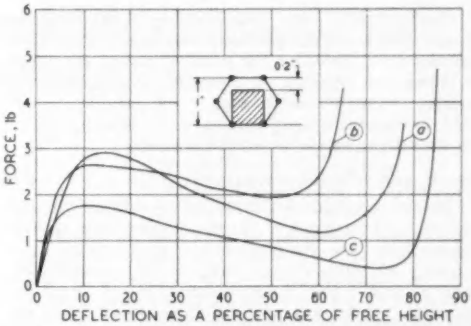


Fig. 6. Force-deflection characteristics of elastic-band buckled-lever systems, curve *a* referring to a two-lever system, curve *b* to a two-lever system with a foam material in compression, and curve *c* to a four-lever (two-way directional) system.

other, using bands of rubber to obtain the resilient effect. Fig. 6 shows the stress-strain curve for such a system, and also the curve for a two-lever system. It will be noted from this illustration that the curves show instability, evidenced by the negative slope of the force-deflection curve; however, this can be overcome by including a material in direct compression in the centre of these configurations. The corresponding stress-strain curve is also shown in Fig. 6. On the other hand, force-deflection curves with negative slopes may be useful in certain non-packaging applications requiring a system that gives way if a specified force is exceeded.

In general, buckled-lever configurations can in many cases approximate materials with constant restoring forces fairly well. However, they are subject to some practical difficulties—most important being the problem of obtaining restrainers with the proper hinging action, without weakening the assembly excessively.

Columnar Systems

The elastic instability of columns under compressive loads is another concept that can be employed to obtain constant-force characteristics. A column becomes unstable and buckles if the applied compression load exceeds a certain critical value. During the buckling that follows, the column exerts a resisting force nearly equal to the critical force, and nearly constant for a considerable range of the deflection.

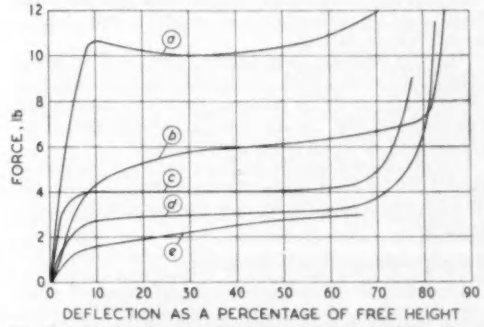


Fig. 7. Force-deflection characteristics of buckled-column systems.
Curve *a*: 4 red-rubber columns, 1 × 1½ × ⅛ in.
Curve *b*: 2 polythene columns, 1 × 2 × ⅛ in.
Curve *c*: 16 red-rubber columns, 1·4 × ¼ × ⅛ in.
Curve *d*: 4 gum-rubber columns, 1 × 1·45 × ⅛ in.
Curve *e*: 4 polythene columns, 1 × 7½ × 1/16 in.

Configurations employing columns as the buckling elements are easily designed and built to provide a wide constant-force plateau. The columns consist of rubber or rubber-like platelets, so arranged as to give lateral stability. The curves in Fig. 7 compare the force-deflection performance of various configurations employing different rubber or polythene platelets.

Shock and Vibration Response

Results obtained on a drop-test rig indicate that the buckled-lever material is "harder" and causes greater accelerations than the plain foam for very small drop heights; for greater drop heights, the buckled-lever material is a better shock isolator. Fig. 8 compares drop-test results with results from static tests for materials under column loading.

As materials are generally stiffer dynamically than statically, it is not surprising to find that the force-deflection curves obtained from dynamic measurements lie above those obtained statically. The oscillations evident are a function of the damping inherent in the system. Greater damping obtained in actual use would undoubtedly reduce these oscillations considerably. The curves shown apply only for one particular test.

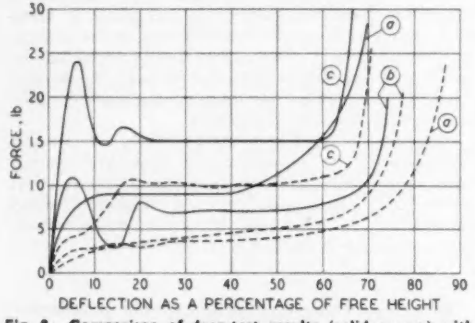


Fig. 8. Comparison of drop-test results (solid curves) with results from static tests (dotted curves) under column loading.
Curves *a*: polyurethane foam.
Curves *b*: polyurethane columnar configuration.
Curves *c*: neoprene columnar configuration.

Comparisons between the vibration-isolation characteristics of the columnar configurations tested and those of two common foams are given in Fig. 9. An equal thickness and volume basis was intended, but the softer foam could not support the static weight, so that a greater volume had to be used.

Results showed good improvement, the columnar configurations reducing transmissibilities at resonance by an order of 2. In contrast, the heavy foam tested behaved virtually linearly over a considerable range, resulting in relatively strong resonance.

Compared with the heavy foam, the larger volume of light foam behaved nearly like the columnar materials. This may be ascribed to the non-linearity inherent in this material.

Package-Design Considerations

Problems in the manufacture of columnar materials are relatively minor, and little trouble has been experienced in obtaining extruded or cast rubber I-beam test samples from processors of commercial rubber and plastics.

These I-beams can be cemented to facing sheets to make up the composite material and, furthermore, lend

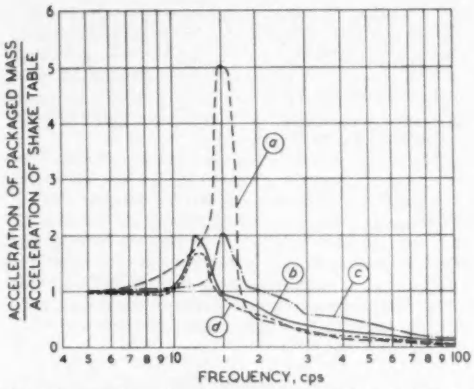


Fig. 9. Comparison of acceleration transmissibility of packaging samples, (*a*) of 1½-in. thick polyurethane foam, (*b*) of a polyurethane column with plastic facing sheets, (*c*) of a neoprene column with corrugated facing sheets, and (*d*) of 2½-in. thick polyurethane foam.

themselves to a rather convenient "glue-it-yourself" application. A given commercial I-beam section might be rated at a plateau force of so many pounds per inch of length, so that selecting the proper length would present no difficulty. To obtain a compact package, various I-beam pieces of the proper total length should be assembled in as closely spaced an array as possible, commensurate with the density of the packaged item. If no I-beam with sufficient deflection capacity is available, the I-beam pads can be placed one on top of the other. Such arrays result in twice or more times the deflection of a single pad, with no reduction in the plateau force.

Rotations caused by shocks experienced when a package is dropped can cause excessive local deflections of the packaging materials, resulting in damage to the packaged item. To reduce damage, the package should be designed so that the line of action of the resultant restoring force always passes through the centre of gravity of the packaged item. With conventional packaging materials this may be difficult to arrange. However, "glue-it-yourself" I-beams can be arranged on a given face of the package envelope so that the centre of gravity of their restoring forces coincides with the projection of the centre of gravity of the packaged item onto that face.

Slag-Welding Technique for Metal Deposition, using Tapered Electrodes

(*Concluded from page 79*)

diameter and 20 mm in thickness in a steel workpiece, using a tapered steel electrode with walls of 7 mm thickness. It was found that, for uniform penetration, the feed rate had to be varied between about 10 and 30 mm/min, this unavoidable variation in feed rate being regarded as one of the present shortcomings of the process. During these tests, welding currents of 35 to 40 V and 500 to 4000 A were used, and the high productivity of the process is indicated by the fact that, with a power of 120 kVA, a deposition rate of 1·1 kg/min was achieved.

It is also claimed that the process is equally suitable for the deposition of alloy cast iron, as well as for various light metals and their alloys.

The Calculation of Natural Circulation in Water-Tube Boilers

By T. WIDELL

From *Teknisk Tidskrift*, Sweden,
Vol. 91, No. 11, March 17, 1961,
pp. 253-256, 6 illustrations.

IN water-tube boilers using natural circulation of water, the intensity of circulation can be expressed in terms of the velocity of the water at the inlet of the steam-generating tubes, or as a circulation factor, i.e., the ratio of the flow rate of the water to that of the steam discharged. Circulation intensity can also be indicated in terms of the steam content of the mixture of steam and water issuing from the tubes.

For cooling the tubes, however, the circulation factor is not of decisive importance, as cooling seems to depend mainly on the relative volume of water, i.e., the ratio of the volume of water to the total volume of water and steam in the tubes. In addition, it is necessary to ensure that a certain minimum flow velocity of water at the inlet of the steam-generating tubes is maintained.

For a given value of the relative volume of water, much higher circulation factors are obtained at low steam pressures than at high pressures. Thus, for example, if 20% volume of water is required, this will necessitate a circulation factor of 21 at 20 atm, whereas only a factor of 3 is needed at 130 atm.

The minimum permissible value of the relative volume of water can depend on a number of factors which are not as yet determined, but it seems likely that a value of 0·2 to 0·25 should generally be sufficient. The inflow velocity of the water in the steam-generating tubes should be at least 0·5 to 1·0 m/sec.

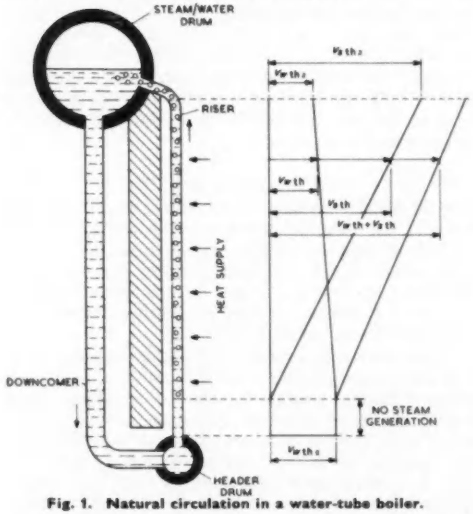


Fig. 1. Natural circulation in a water-tube boiler.

The driving force causing natural circulation is produced by steam generation. In a water-tube boiler (Fig. 1), the water leaving the steam/water drum passes by gravity through the downcomers, which supply it via a header drum to the risers, in which steam is formed by absorption of heat. The density of the mixture of steam and water is less than that of the water in the downcomers, resulting in water circulation. The steam separates from the water in the steam/water drum, which is also provided with pipes for the supply of feed-water and the removal of steam.

By adding feed-water to the boiler-water, the water in the downcomers can be brought to a temperature which is lower than that of steam generation, so that no steam is generated in the lower portion of the riser. In Fig. 1, it is assumed that the heat supply per unit length of riser is constant, so that steam flow increases linearly. Steam flow and water flow are respectively represented by theoretical velocities v_{sth} and v_{wth}, i.e., the values theoretically required for steam and water if each in turn were to fill the tube completely. If the same absolute velocity is used for both steam and water in calculations, its value is then $(v_{sth} + v_{wth})$.

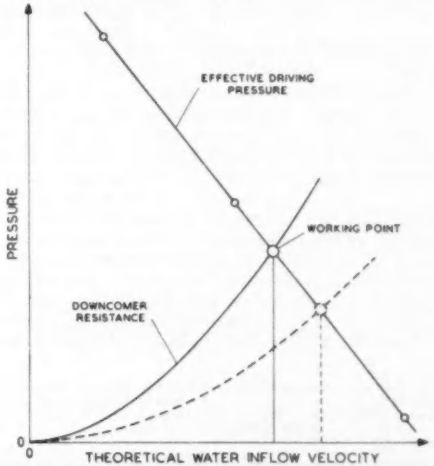


Fig. 2. Graphic method of calculating water circulation in terms of effective driving pressure and downcomer resistanc as functions of the theoretical water inflow velocity v_{wth0}

In principle, circulation is calculated from the effective driving force in the risers and the resistance of the downcomers. It is convenient, however, to refer all quantities to a unit area of cross-section by using values of velocity instead of flow rate, and pressure instead of force (Fig. 2). The effective driving pressure is obtained as the difference between the vapour pressure of the steam bubbles and the flow losses in the riser. The intersection of two curves, respectively representing effective driving pressure and downcomer resistance determines the working point. Should it be found that this gives too little flow, it will then be necessary to reduce the resistance of the downcomers by increasing their diameter or by increasing the number of downcomers, as shown by the dotted curve in Fig. 2.

If the steam bubbles and the water in the riser had the same velocity, the calculation would be simple, since it is easy to calculate the density of the steam/water mixture if the amount of heat supplied is known. The steam bubbles, however, always tend to rise through the water; a relative velocity is therefore obtained which increases

the density of the mixture and thus reduces the driving pressure. The velocity with which the steam bubbles rise has been the subject of many investigations. In addition, measurements have been made on steam boilers and model apparatus to determine circulation and relative velocities.

Relative velocity under different conditions has been used as a basis for various calculation methods and also for diagrams facilitating evaluations. Even with these computational aids, however, calculations of circulation based on relative velocity have remained very involved and difficult to visualize. A convenient and time-saving calculation method has now, however, been found and has given good results when applied to various boiler plants recently investigated experimentally.

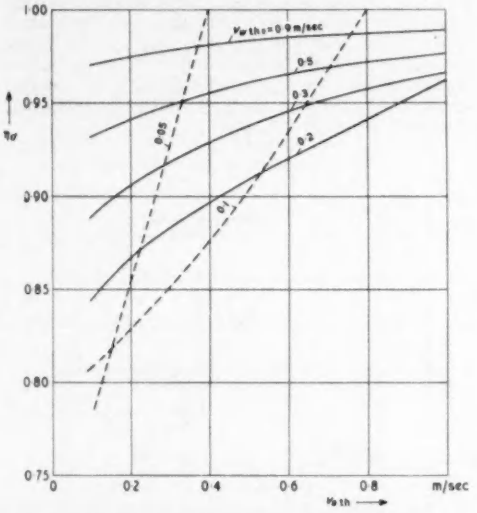


Fig. 3. Driving-pressure efficiency η_d as a function of theoretical steam velocity v_{sth} for different values of theoretical water inflow velocity v_{wth0}, with a tube diameter of 56 mm and a steam pressure of 130 atm.

This calculation method is based on driving-pressure efficiency η_d, which is defined as the ratio of effective driving pressure p_{eff} to the driving pressure p_d that would be obtained if there were no relative velocity between the steam and water. The driving pressure p_d is determined from the height H of the riser, the steam density ρ_s, the water density ρ_w, and the density ρ_m of the steam/water mixture (with no relative velocity), by means of the relation

$$p_d = \eta_d \, gH \, (\rho_w - \rho_m) \quad .. \quad .. \quad .. \quad (1)$$

The density of the mixture ρ_m (with zero relative velocity) is obtained from

$$\rho_m = (\rho_s v_{sth} + \rho_w v_{wth})/(v_{sth} + v_{wth}) \quad .. \quad (2)$$

so that

$$\rho_w - \rho_m = (\rho_w - \rho_s) \, v_{sth}/(v_{sth} + v_{wth}) \quad .. \quad (3)$$

While steam velocity v_{sth} increases from an initial value of zero, water velocity v_{wth} decreases from its initial value v_{wth0}. This gives the relation

$$v_{wth} = v_{wth0} - (\rho_s/\rho_w) \, v_{sth} \quad .. \quad .. \quad .. \quad (4)$$

It is now necessary to evaluate the pressure loss p_L, which, in general, can be obtained from the expression

$$p_L = 1{\cdot}5\rho_w \frac{v_{wth0}^2}{2} + \lambda \frac{L}{D} \rho_m \frac{v_m^2}{2} + \rho_w v_{wth0}(v_2 - v_1) \quad (5)$$

where λ is the friction loss factor, L is the tube length and D its diameter, and v_m is the velocity of the steam/water mixture. In eq. (5), the first term represents inflow losses of water and losses due to acceleration. The second term represents friction losses, and, from experimental and calculated data available, it appears that the mixed-flow conditions in the riser can be represented by a friction loss factor λ of 0·032. The third term represents the drop in accelerating pressure and contains the true velocities v_1 and v_2. If it is required that the steam velocity be zero, then $v_1 = v_{wth0}$. Frequently, however, owing to non-uniform thermal loading, for instance, it is necessary to split up the calculation into several stages. The calculation is then made for an acceleration corresponding to an increase in steam velocity from v_{sth1} to v_{sth2}.

The pressure losses are calculated by means of eq. (5) without using relative velocities, so that the absolute velocity v is expressed as

$$v = v_{sth} + v_{wth} \quad .. \quad .. \quad .. \quad .. \quad (6)$$

Consequently, with the aid of eqs. (2) and (6), a more convenient form can be obtained for the calculation of the second term in eq. (5), i.e.,

$$\rho_m \frac{v_m^2}{2} = \rho_w \frac{v_{wth0}}{2}\left[1 + \left(1 - \frac{\rho_s}{\rho_w}\right)\frac{v_{sth}}{v_{wth0}}\right] \quad .. \quad (7)$$

where v_{sth} is a mean theoretical value.

The acceleration losses can be derived from

$$\rho_w v_{wth0}(v_2 - v_1) = (\rho_w - \rho_s) \, v_{wth0} \, (v_{sth2} - v_{sth1}) \quad (8)$$

From the value of driving pressure p_d, calculated from eq. (1), and the total losses in the riser, obtained from eq. (5), it is then possible to calculate the effective driving pressure p_{eff} from

$$p_{eff} = p_d - p_L \quad .. \quad .. \quad .. \quad .. \quad (9)$$

and the relation between p_{eff} and water velocity is then used for the graphical solution shown in Fig. 2.

The driving-pressure efficiency η_d in eq. (1) depends on a number of different factors, and its values must be obtained from practical tests. As it is not possible to measure the driving pressure p_d directly, its value is determined by means of eq. (9).

From the results of such tests, and the calculation of pressure losses by means of eq. (5), with λ = 0·032, the effective driving pressure p_d can be obtained. This enables the driving-pressure efficiency η_d to be determined as a function of steam and water velocities, and the resulting curves can then be plotted, as shown in Fig. 3. This diagram, however, is valid only for a specified value of steam pressure and a similar diagram must be calculated for any other steam pressure.

Fig. 3 shows that the driving-pressure efficiency η_d increases with increasing values of water velocity v_{wth0} and higher steam velocities v_{sth}, provided that the water velocity is not too low. For very low values of v_{wth0}, the η_d-curves follow a different trend, as shown by the dotted lines in Fig. 3 and can reach unity at a certain point. These points correspond to conditions of complete evaporation of the water, and the relation between v_{wth0} and v_{sth} is then given by eq. (4), with $v_{wth} = 0$.

(Concluded on page 123)

Slag-Welding Technique for Metal Deposition, using Tapered Electrodes

By A. Ya. Shwartzev

From *Svarochnoye Proizvodstvo*, Russia, No. 3, March 1961, pp. 17–19, 8 illustrations.

Although the slag-welding process was originally intended for the vertical seam-welding of heavy plates and for other constructional work, a recently developed adaptation makes it possible to extend the use of this process to surfacing and building up large horizontal areas, and also to the reclamation of worn dies and machine components. Basically, this adaptation employs the same technique as conventional slag-welding but, instead of plate or wire electrodes, utilizes special tapered electrodes produced by casting or by pressing or fabricating from sheet steel or other materials.

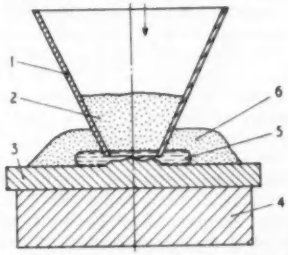


Fig. 1. Schematic arrangement of the metal-deposition process, using tapered electrodes.

Fig. 1 shows the schematic arrangement of the process, in which the tapered electrode (1) is filled with a granular flux (2) and is fed vertically towards the workpiece (3), which rests on a support (4). During operation, the electrode and the workpiece are connected to the source of current, welding being initiated by arcing and continued under a shield of molten slag, the weld pool (5) being also externally covered with flux (6).

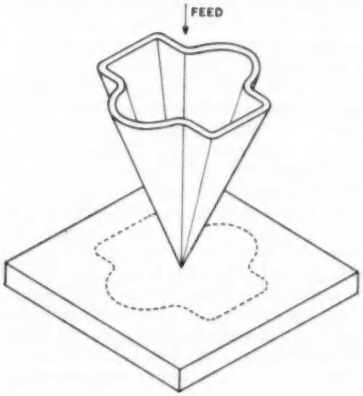
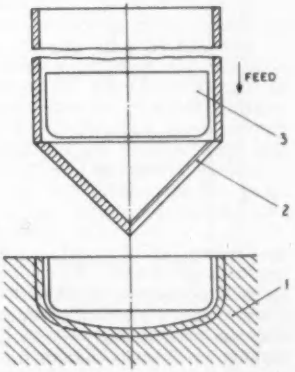


Fig. 2. (Left) **Example of a tapered electrode for building up a complex shape.**

Fig. 3. (Right) **Combined tapered and cylindrical electrode for building up a stamping die.**



The thickness t of the electrode can be calculated from the equation $t = S \sin \frac{1}{2}\alpha$, where S is the thickness of the weld deposit and α is the apex angle of the tapered electrode. For practical considerations, it is recommended that the thickness t of the electrode be in the range between 5 and 20 mm. It is also possible to use double-walled electrodes, the intervening space being filled with a suitable powdered alloy. The shape of the electrodes can be varied in accordance with the requirements of the areas to be built up. For example, conical electrodes can be used for circular areas, while electrodes in the form of truncated cones can be used for annular areas. In the case of complex shapes, the shape of the electrode can be matched to follow that of the original area, as shown in Fig. 2.

It is also possible to combine a tapered electrode with a tubular electrode for applications in which both horizontal and vertical surfaces must be built up. A typical example of the use of such a combined electrode is shown in Fig. 3, which illustrates a stamping die (1) whose base is built up by means of the conical section (2) of the electrode, and the walls by means of the cylindrical part, the thickness of the vertical deposit being controlled by an insert (3).

In general, metal deposition or surfacing can be carried out with existing manual equipment. However, for applications where accurate positioning of the electrode and workpiece is essential, a special stand has been designed, in which vertical movement of the welding frame, as well as linear alignment of the workpiece and angular alignment of the electrode, can be controlled with considerable accuracy.

If metal deposition is carried out with small tapered electrodes, automatic welding heads, such as those used in the conventional submerged-arc welding process, can be employed. In this case, the method adopted is to use a tapered electrode fixed to an extension rod which is clamped in the feed mechanism of the welding head, thus transmitting a vertical feed to the electrode.

The parameters of the process of metal deposition with tapered electrodes are in many respects identical with those encountered in conventional slag-welding, but certain characteristics, owing to the variation in the cross-section of the electrode, are entirely different, so that many of the operating parameters have to be determined experimentally. In this connection, it may be mentioned that a series of tests was carried out with the new process to build up a circular area of 200 mm in

(*Concluded on page 76*)

A New Test Method for Determining the Spinnability of Metals

By R. L. KEGG

From *Journal of Engineering for Industry, Trans. ASME*, Vol. 83, Series B, No. 2, May 1961, pp. 119–124, 11 illustrations.

ONE of the greatest applications of the shear-spinning process is the forming of aircraft and missile components, many of which are of newly developed alloys having good high-temperature structural properties but limited room-temperature ductilities. In the past, however, there has been no well-defined method for predicting whether or not a particular material can be shear-spun to a particular shape without fracture. As a result, there has been considerable waste in development work by trial-and-error methods from which only vague conclusions can be drawn, and it therefore would be of value to use a simple and inexpensive test method to determine the ductility of a material under shear-spinning conditions. Such a test method is described in this article, making it possible to determine the spinnability of any material, i.e., its ability to undergo shear-spinning deformation without fracture.

The familiar "sine law", as applied to spinning, states that the volume of material remains constant during spinning and that each increment of volume must retain its radial distance from the centre of rotation—a condition which must be imposed on the operation by making the proper machine settings. Although this sine law is only a geometric relationship which describes an ideal change of shape, experience has shown that it must be obeyed rather closely. While some deviation from this rule is possible, the best product is usually obtained at or near sine-law conditions.

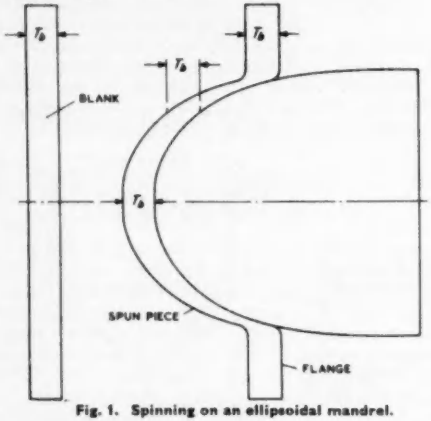


Fig. 1. Spinning on an ellipsoidal mandrel.

To carry out tests, a spinning mandrel was constructed in the shape of a half-ellipsoid, as shown in Fig. 1, an ellipsoid being chosen because it is essentially a cone mandrel which varies infinitely in included angle between 180 and 0 deg. According to the sine law, a workpiece spun on this mandrel must vary gradually from its original thickness to zero. If percentage reduction in thickness R is defined as

$$R = 100\,(T_b - T)/T_b \quad .. \quad .. \quad .. \quad (1)$$

where T_b is the original blank thickness, and T is its final spun thickness, then the reduction on this mandrel must vary gradually from 0 to 100%. Obviously, all materials must fracture somewhere between these limits, since a 100% reduction corresponds to infinite strain.

This mandrel was mounted on a shear spinning machine with two forming rollers, each of which has a force of approximately 50,000 lb available parallel to the spindle centre line and 50,000 lb perpendicular to the centre line. A 100-hp a.c. motor drove the mandrel through a hydraulic variable-speed unit. The path of the rollers was controlled by two templates having the same shape as the mandrel, but shifted parallel to the axis of rotation by an amount equal to the original thickness of the workpiece. From Fig. 1, it can be seen that this condition satisfies the sine law, where the final part thickness measured parallel to the axis of rotation has a constant value equal to the original blank thickness.

Test-pieces of ¼-in. plate materials were shear-cut to 12-in. squares. Strips were cut from the edges of each piece for mechanical testing and a pilot hole was drilled in the centre of the plate. Each piece was marked with a code number and the Brinell hardness was measured to identify the condition of the material.

In spinning the specimens, three important factors were controlled by adjustment of machine variables, in order that values obtained in the test would be applicable to spinning practice and comparable with each other. Thus, the wall thickness at each point was adjusted as nearly as possible to the value required by the sine law. This is very important at the point of fracture, since deviations from the sine law cause more complex states of stress and strain to exist under the roller. This variable was controlled by the template setting, and movement of the tracer body by a calibrated screw. It was also necessary to ensure that the spun part should fit well on the mandrel, because this is desirable in spinning practice and should therefore be a criterion of any spinning test, and because, when the part fits tightly on the mandrel, it must have the same shape as the mandrel and this eliminates extensive measurement of spun parts. This factor was controlled by holding correct wall thickness and varying feed and rotational speed.

Finally, for a good test, the unspun flange or undeformed portion of the workpiece must remain plane. Often, the flange will lean forward towards the headstock unit, or backward away from the headstock unit. This phenomenon is usually associated with deviations from the sine law, but it is known that, even when the thickness is correct, certain combinations of the process variables may cause flange bending. This is to be avoided, since it "preforms" the part and changes the thickness required by the sine law.

The first specimen of each material was formed under conditions estimated from past experience and was usually a poor part. Corrections were made and the second part was spun. This procedure was repeated until a good part resulted and, with this set of conditions, the remaining test-pieces of the particular material were spun. For each test, the machine set-up data were recorded, and the thickness at fracture and the height of the spun cup were measured.

Tensile tests were performed on material from each

spinnability test-specimen. Testing was done on a 60,000-lb universal tensile testing machine, using a specimen with a gauge section of $\frac{1}{4} \times \frac{1}{2}$ in. and a gauge length of 2 in. A constant cross-head movement rate of $\frac{1}{8}$ ipm was used. The complete load-elongation curve was recorded for each specimen, and the reduction of cross-sectional area at fracture was measured.

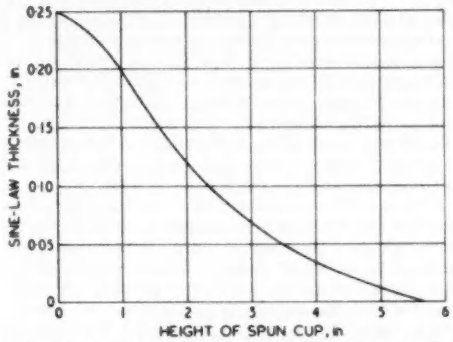


Fig. 2. Sine-law thickness for a $\frac{1}{4}$-in. blank as a function of the height of the spun cup.

The ideal thickness, i.e., the sine-law thickness, of a $\frac{1}{4}$-in. blank as a function of the height of the spun cup is shown in Fig. 2, making it possible to read directly the correct wall thickness at fracture for any height of cup. However, comparison of the actual value of thickness obtained from measurements revealed that few of the parts were spun exactly to sine-law conditions. Consequently, to interpolate these results to standard sine-law conditions, a parameter K of deviation from the sine law was introduced and is expressed as

$$K = T_m/T_s \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where T_m is the measured thickness, and T_s is the sine-law thickness.

When the actual reduction of wall thickness at fracture for each test-piece of a single material is plotted graphically against the parameter K, a consistent relationship is obtained which may be interpolated to the desired value of reduction for $K = 1$. The value thus obtained is the average limiting reduction for the particular material when spun according to the sine law. Such a graph shows that an increase in the value of K lowers the maximum permissible reduction, while an increase in the value of K increases the maximum permissible reduction.

This phenomenon is readily explained by considering the geometry of shear spinning and the geometry of deviation from the sine law. Fig. 3 shows the cross-section of a blank of thickness T_b and diameter $2R_b$,

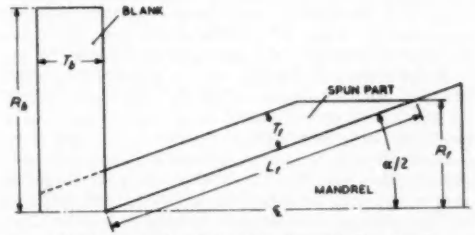


Fig. 3. Geometry of deviation from the sine law.

which is spun into a cone of angle α having any height ($L_f \cos \frac{1}{2}\alpha$) and any thickness T_f. The three components of strain are thickness strain e_T, length strain e_L, and circumferential strain e_C, which can be expressed as follows:—

$$e_T = \frac{T_f}{T_b} - 1 \quad .. \quad .. \quad .. \quad .. \quad (3a)$$

$$e_L = \frac{L_f}{R_b} - 1 \quad .. \quad .. \quad .. \quad .. \quad (3b)$$

$$e_C = \frac{R_f - R_b}{R_b} = \frac{L_f \sin \frac{1}{2}\alpha}{R_b} - 1 \quad .. \quad (3c)$$

Using eq. (2) for the parameter K,

$$T_m = T_f = KT_s = KT_b \sin \tfrac{1}{2}\alpha \; .. \quad .. \quad (4)$$

so that

$$e_T = K \sin \tfrac{1}{2}\alpha - 1 \quad .. \quad .. \quad .. \quad (5)$$

The constancy of volume is expressed by

$$(1 + e_T)(1 + e_L)(1 + e_C) = 1 \quad .. \quad (6)$$

and therefore

$$(K \sin \tfrac{1}{2}\alpha)\left(\frac{L_f}{R_b}\right)\left(\frac{L_f \sin \frac{1}{2}\alpha}{R_b}\right) = 1 \quad .. \quad (7)$$

$$\text{or} \quad L_f = \frac{1}{\sqrt{K}}\left(\frac{R_b}{\sin \frac{1}{2}\alpha}\right) \quad .. \quad .. \quad .. \quad (8)$$

from which, in conjunction with eq. (3c),

$$e_C = \frac{1}{\sqrt{K}} - 1 \quad .. \quad .. \quad .. \quad (9)$$

With the sine law, $K = 1$ and $e_C = 0$ but, if $K < 1$, then $e_C > 0$. This means that the part must undergo tensile deformation in the circumferential direction. If fracture does not occur immediately, the unspun flange must also undergo this type of deformation. The resistance of the flange to this deformation causes radial compressive stresses to act on the zone undergoing spinning deformation. It has been shown that the addition of a compressive component of stress to a plastic deformation process will increase the ductility of metals under the process. Thus, when the wall thickness is less than that required by the sine law, tensile circumferential strains are caused in the unspun flange, and ductility is increased. It can be shown by similar reasoning that, when the wall thickness is too great, compressive circumferential strains are imparted to the flange, and ductility is decreased.

The circumferential compressive strains in the flange as a result of too little reduction explain flange-wrinkling in extreme cases, since less energy is required to wrinkle the flange than to shrink it, as in deep drawing. On the other hand, when the part is over-reduced, less energy is consumed by the flange leaning forward or backward than by growing in diameter in a radial plane. This is also consistent with experience in the spinning of production parts.

The values of limiting reduction obtained in this work are generally higher than those obtained in practice. This is believed to be due to two features inherent in this test method which are not extensively employed in spinning practice. One feature is the gradual change in cross-sectional area which the material undergoes on this ellipsoidal mandrel. It is a well-known design principle that sudden changes in section weaken structures, and it

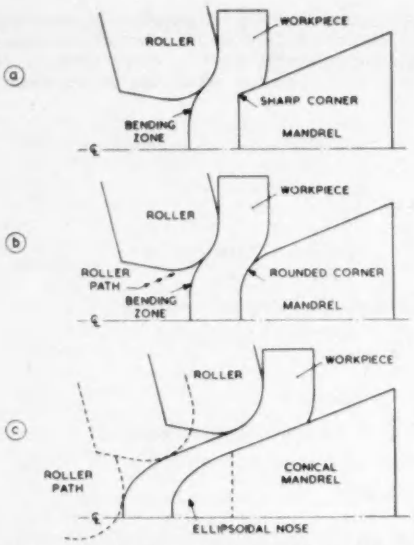


Fig. 4. Geometry of the mandrel nose, (a) for a sharp-corner mandrel, (b) for a rounded-corner mandrel, and (c) for a conical mandrel.

seems that this may also apply to parts which are undergoing spinning deformation. The second beneficial feature of this test method is the fact that true shear spinning is maintained at each point during the operation. Fig. 4a shows how bending is introduced when a part is formed over a mandrel having a sharp edge from nose to wall, while Fig. 4b shows that bending is still present when a radius is put on the mandrel. In Fig. 4c, an improved design for conical spinning mandrels is shown, where the wall thickness is tracer-controlled to decrease gradually from its original value to the value which the sine law requires for the desired cone. The sine law is maintained at each point according to the instantaneous included angle of the mandrel, i.e., the axial measurement of thickness is always equal to the original blank thickness.

A plot of maximum thickness reduction in spinning against maximum reduction of area in the tensile test (Fig. 5) shows a rather consistent relationship between these two quantities. For materials having tensile reductions of 80% or less, the limiting spinning reduction is equal to or greater than the limiting tensile reduction. Less ductile materials will fracture at greater cone angles where, it seems, a state of stress exists which is more conducive to large deformations than in the tensile test. However, for more ductile materials, which fracture at small cone angles, the state of stress at fracture seems to approach pure tension. This was confirmed by the observation that materials which withstood large strains and spun to low angles fractured behind the forming roller in tension, while materials which fractured at large cone angles failed under the roller at some other deformation limit.

A plot of percentage tensile elongation in 2 in. against maximum spinning elongation showed no trend whatsoever, so that percentage elongation by itself may not be used as a criterion for spinnability. This might be expected, since the value of percentage elongation will change considerably for various gauge lengths and by itself cannot be related to the maximum strain taking place in the tensile bar before fracture. Thus, it appears that the tensile-test reduction of area is at present the best known indicator of spinnability. The curve in Fig. 5 may be approximated by the relationship:—

$$R = \frac{q}{0{\cdot}17 + \frac{q}{100}} \quad .. \quad .. \quad .. \quad .. \quad (10)$$

where R is the limiting reduction of spinning [%] and q is the tensile-test reduction of area at fracture [%]. From this relationship, it is possible to estimate the maximum spinning reduction a material will withstand, knowing only the tensile property of reduction of area at fracture. It is known that this value will vary for different tensile-specimen geometries, but the specimen used in this work is convenient for use with plate and sheet materials and should be easy to duplicate.

Tests have been carried out on a number of materials, including aluminium alloys, copper, and stainless and other steels, and their average properties obtained from tensile testing and their average ductility values obtained from spinnability testing have been compared. Examination of the results shows that there is no relationship between spinning ductility and such properties as strength and strain-hardening rate as measured by the logarithmic strain corresponding to the ultimate tensile strength. It should also be noted that the results obtained in tests on the spinnability and tensile properties of two specimens each of René 41 (a nickel-base alloy and heat-treated 17-4 PH stainless steel did not seem to fit

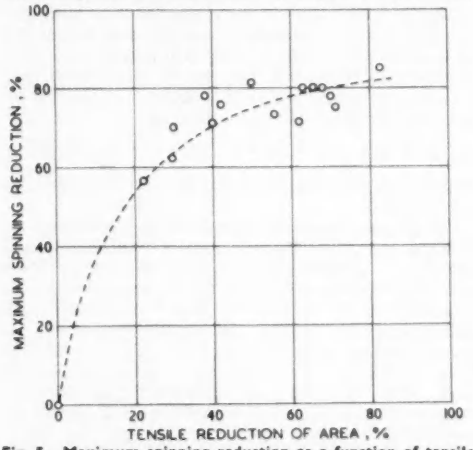


Fig. 5. Maximum spinning reduction as a function of tensile reduction of area.

the curve in Fig. 5. However, the use of only two specimens did not permit a good plot of the deviation parameter K as a function of maximum spinning reduction R to be obtained, and the values of spinnability were questionable. Also, these materials exhibited very low ductility in spinning in a direction at 45 deg. to the apparent direction of rolling of the sheet. Since shear spinning has rotational symmetry, the least ductile direction is the one which will cause fracture, and tensile specimens were not available in this direction for a comparison of spinnability and tensile ductility. It was apparent, however, that these materials in the condition used in this work must be spun at elevated temperatures if a large amount of deformation is desired. It is therefore

(*Concluded on page 87*)

The Hot-Machining of Metals

By R. C BREWER*

ANY machining difficulty arising from a deficiency in the power of a machine tool can be resolved by transferring the workpiece to a higher-powered machine. Consequently, the only real reflection of difficulty in machining is a short tool life, i.e., one which, under average conditions, is of a quite different order to that obtaining for general engineering materials. High-temperature materials in particular fall into this category, and their increasing use and the constant tendency towards operation at higher temperatures have produced a problem which has been stated (with a colloquial conciseness typical of the U.S.A.) as "machining the unmachinable".

The newer tool materials, such as the super-carbides and ceramics, have enabled increased cutting speeds to be used when machining many conventional materials. Unfortunately, the superior abrasion resistance which has permitted these increases in cutting speed is accompanied by a reduction in toughness, and the new tool materials *per se* have not solved to any appreciable extent the problems of machining high-strength, high-temperature alloys.

It became increasingly clear that some serious change would have to be made in one of the factors governing machining operations, and the following three main approaches have been tried:—

(a) *Sub-Zero Coolants:*—These represent an attempt to lower the equilibrium temperature of the tool during machining by using a mist or flood of coolant at a temperature of around −70°F.

(b) *Ultra-High Cutting Speeds:*—In this case, the basic parameter of cutting speed is increased to such an extent that the easiest experimental method to employ is to use a modified firearm to project the workpiece past the tool.

(c) *Hot-Machining:*—Here, the temperature of the workpiece is raised several hundred degrees above ambient, so as to reduce the shear strength of the material. This is the only approach that will be considered in any further detail in this article.

Historical Note

For many years, billets in steel mills were sawn while still hot, because it was observed that cutting rates were considerably increased in this way. However, no serious consideration was given to hot-machining until the early post-war years, when a preliminary investigation by the Battelle Memorial Institute established the feasibility of using heat to facilitate the machining of high-temperature alloys. The well-known company of turret-lathe builders, Warner and Swasey, then sponsored a further programme of research at Battelle, lasting from the spring of 1945 to the autumn of 1946.

1946 saw the granting of what appears to be the first patent in this field[1] (for a method of induction heating) and a proposal to the U.S. Navy by Sam Tour and Co. for a programme of research into hot-machining. Between 1946 and 1949, programmes were undertaken by Sam Tour[2], by Armstrong, Cosler, and Katz[3] at Battelle, and by Armitage and Schmidt[4] at the Kearney and Trecker Company in Milwaukee.

These investigations showed a considerable reduction in tool forces but did little to study the fundamental reasons for it. Furthermore, Armstrong *et al.* were the only investigators to give any tool-life information of real value. In an attempt to add to fundamental knowledge of machining workpieces at elevated temperatures, Krabacher and Merchant[5] carried out a short investigation at the Cincinnati Milling Machine Company and reported their findings in 1951. The whole matter then lay dormant until 1957, when this company conducted surveys of the U.S. aircraft industry and found a need for further research. A programme, guided initially by this survey, has been carried out almost continuously since 1957, and has been supported by the Air Materiel Command from September 1959 onwards[6].

A number of materials are known to cause trouble in conventional machining operations, the chemical composition of some of those used in hot-machining studies being given in Table I, which includes their hardness and, where possible, their corresponding yield strengths at different temperatures, as derived either from machining data or conventional materials tests.

Although the earlier investigations did not yield very satisfactory data from a quantitative point of view, they showed that the machining of workpieces at elevated temperatures led, in general, to a reduction in machining power and an increase in tool life. It is therefore of interest to consider the effects of elevated temperatures in the light of the generally accepted mechanics of machining at practical cutting speeds[7].

Machining Operations at High Temperatures

Fig. 1a shows the physical details of an orthogonal machining operation (i.e., one in which the cutting edge is perpendicular to the directions of both feed and cutting speed), together with the components of the resultant force between the tool and workpiece along and perpendicular to the shear plane F_s and F_n or, alternatively,

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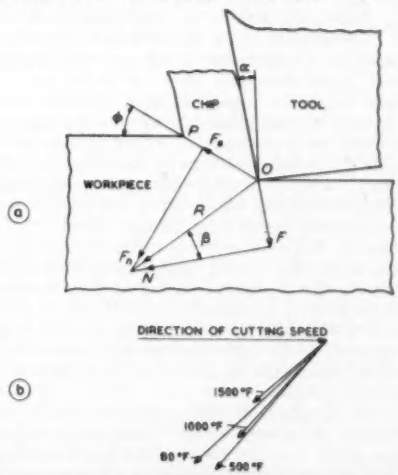

Fig. 1. Physical details of an orthogonal machining operation, showing (a) resolution of the resultant force, and (b) variation of the resultant force with workpiece temperature.

TABLE I: COMPOSITION AND PROPERTIES OF SOME MATERIALS USED IN HOT-MACHINING STUDIES

	AISI 4340	Timken 16-25-6	S 816	Inconel X	Thermold J	17-4-Mo	17-7 PH
Chemical Composition [%]							
Carbon	0·43	0·08–0·10	0·4	0·08 max.	0·5	0·10	0·07
Manganese	—	2·0 max.	1·0	0·3–1·0	0·4	—	0·65
Silicon	—	1·0 max.	0·4	0·5 max.	1·1	—	0·5
Chromium	0·8	16·0	19·8	14·0–16·0	5·0	17·0	17·0
Nickel	1·8	25·0	20·2	70 min.	1·5	4·0	7·0
Molybdenum	0·25	6·0	4·3	—	1·4	3·0	—
Aluminium	—	—	—	0·4–1·0	—	—	1·0
Iron	96·72	Balance	3.5	5·0–9·0	89·1	75·75	73·78
Titanium	—	—	—	2·25–2·75	—	—	—
Tungsten	—	—	4·3	—	—	—	—
Columbium	—	—	3·8	0·70–1·25	—	—	—
Cobalt	—	—	42·3	—	—	—	—
Vanadium	—	—	—	—	1·0	—	—
Copper	—	—	—	0·2	—	—	—
Sulphur	—	—	—	0·01	—	—	—
Nitrogen	—	0·15	—	—	—	0·15	—
Yield Strength [psi]							
at 68°F	180,000	95,000	—	—	250,000	180,000	200,000
at 500° F	170,000	81,000	—	—	240,000	180,000	170,000
at 1000°F	110,000	65,000	—	—	180,000	110,000	130,000
Brinell Hardness	390 or 600	266	282	203	390 or 600	380	390

along and perpendicular to the rake face F and N.

The shear force gives rise to a shear stress of magnitude F_s/A, where A is the area of the shear plane, of which OP is a trace in Fig. 1a. This shear stress is, in fact, the stress necessary to sustain the flow of material under the local conditions pertaining at the shear plane. The shear stress, multiplied by the shear strain, gives the work done in shear for each cubic inch of material removed. The results of Krabacher and Merchant showed that the shear stress along the shear plane decreased markedly as the workpiece temperature was increased, but it is also necessary to know how the shear strain varies before it is possible to deduce the amount by which the shear work decreases with an increase in workpiece temperature. Although Krabacher and Merchant do not give figures for the shear strain, they do, fortunately, provide enough data to enable it to be evaluated. Their results show that, within experimental error, shear strain does not vary with change in temperature. Consequently, the work needed for shearing decreases with temperature at virtually the same rate as the yield shear stress (Fig. 2).

Most engineers would probably feel this intuitively (albeit with no real knowledge of how the shear strain varies with temperature), but it is more difficult to foresee how the frictional conditions at the chip-tool interface will vary. Krabacher and Merchant's results indicated that, with increasing temperature, the friction angle β first increased, reached a turning point, and then decreased. Variation in the friction angle is to be expected, since the rubbing conditions at the tool face are very severe and it is quite unreasonable to suppose that Coulomb friction is operative. It is, however, common experience that the real area of tool-chip contact is almost equal to the apparent area under the conditions pertaining in machining, and thus the friction force is usually fairly constant.

It will be seen from Fig. 2 that the friction force F also shows an increase before subsequently decreasing. At first sight, it might be expected that increasing the temperature would cause a continuous decrease in friction force, but this presupposes that the frictional effect is always due to the same kind of weld between high spots of the contacting materials. In fact, these welds will be "pressure" or "temperature" welds, depending on whether the local temperature is below or above the temperature of recrystallization. The former type of weld will be more difficult to break during sliding because of the work-hardening associated with deformations which occur below the temperature of recrystallization.

This picture of pressure and temperature welds is, then, in accord with the calculations made from Krabacher and Merchant's results, which are shown in Fig. 2 and from which it will be noted that the hump in the friction-force curve is reflected in that pertaining to the work done against friction.

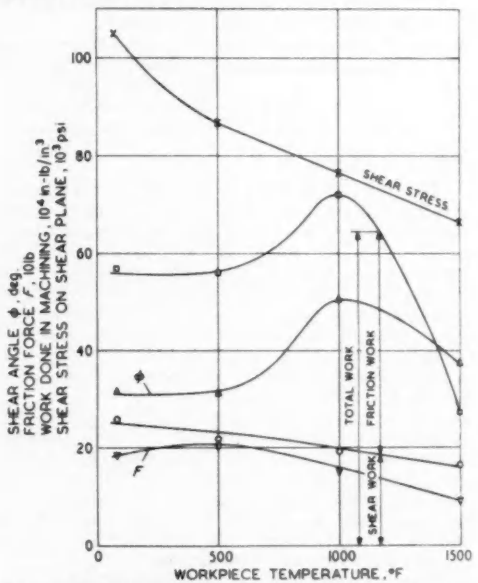

Fig. 2. Relation between various factors and workpiece temperature during machining.

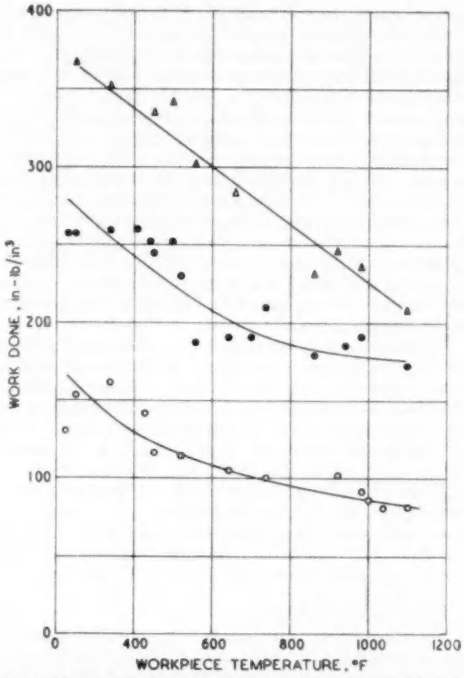

Fig. 3. Influence of workpiece temperature on work done during machining, showing friction work (open circles), shear work (solid circles), and total work (triangles).

The results reported by Pentland, Wennberg, and Mehl[8] are reproduced in Fig. 3, from which it will be seen that they do not show any hump in the curves for friction work and total work. They are therefore not in so obvious an agreement with the picture of pressure and temperature welds, but it must be admitted that the apparatus used by these investigators should have given more reliable results than those of Krabacher and Merchant. Moreover, the fact that the hump in the friction-work curve in Fig. 2 coincides with the oddly high value of shear angle φ at 1000°F would be extremely suspect, were it not for the fact that the shear strain calculated from it is consistent with the other three values at 80°, 500°, and 1500°F.

Most investigators seem to agree that decreases of from 40 to 60% are observed for cutting forces and cutting power, and Pentland shows photographs indicating how much the process of plastic deformation is assisted by elevated temperatures. Fig. 1b shows how the resultant cutting force varies, in both magnitude and direction, with workpiece temperature.

Comparatively little attention had been paid to the question of tool-chip interface temperature until the recent investigations sponsored by the Air Materiel Command. It is true that Krabacher and Merchant had calculated this interface temperature, but they used an early thermodynamic theory of machining which, although a big step forward at the time, is now known to be unsatisfactory in many respects.

If it is assumed that the whole of the shear work reappears as heat at the shear plane, then a simple calculation shows that the general level of temperature along the shear plane increases as the workpiece temperature is raised, but at a lower rate. It would be quite invalid to apply similar reasoning in determining the chip-tool interface temperature, since the bulk of the friction work heats a comparatively thin zone of the chip adjacent to the rake face of the tool. It is impossible to make anything but a wild guess about the thickness of this zone and consequently it is impossible to obtain even a rough guide to the general level of temperature at the chip-tool interface.

Evidence from more refined approaches is conflicting. Krabacher and Merchant found an optimum workpiece temperature, inasmuch as the interface temperature was a minimum at a workpiece temperature of about 500°F. Furthermore, for a rise in workpiece temperature from ambient to 1000°F, they found that the interface temperature increased by about 350°F at a cutting speed of 286 fpm but decreased slightly at 550 fpm.

Pentland[8] reports only increases in interface temperature, the general picture of these increases for an increase of workpiece temperature of 1000°F for different materials being as follows:—

Workpiece Material	Increase in Interface Temperature
Thermold J	250–300°F
AISI 4340	700–1000°F
17–7 PH	300–700°F
17–4–Mo	600–1100°F

These results were obtained experimentally, using the tool-chip thermo-couple technique.

Effect of Workpiece Temperature on Tool Life

Many investigators, commencing with Schallbroch, Schaumann, and Wallichs[9], have established that tool life is a function of the average chip-tool interface temperature. In fact, it varies according to approximately the twentieth power of the interface temperature. In view of this great sensitivity of tool life to changes in interface temperature, it might be expected that one of the more obvious consequences of heating the workpiece would be to cause a drastic reduction in tool life. It should be remembered, however, that the general mechanism of tool failure is that the abrasive action of the workpiece gradually wears the tool on the flank or clearance face, so that the temperature in question is the one at the interface between the workpiece and the tool.

The twentieth-power law was established with workpieces at room temperature, and under these conditions a correlation between the important clearance-face temperature and the measured rake-face temperature might pertain. The effect of varying the workpiece temperature over a wide range (from ambient to 1500°F) will be to alter considerably both the abrading characteristics of the work material and the general level of clearance-face temperature. The balance between these factors will determine whether the tool life at a given workpiece temperature will be increased or decreased by a small rise in workpiece temperature. This is illustrated in Fig. 4, which is reproduced from Krabacher and Merchant's paper, and shows tool life (metal removal for 0·03-in. wear) as a function of workpiece temperature. For each cutting speed, there is an increase in tool life up to a workpiece temperature of about 500°F, but, beyond this value, any further increase in workpiece temperature reduces the tool life.

Curves of tool life as a function of cutting speed have the same general shape for hot-machining as for machining at room temperature[10], i.e., they exhibit a maximum

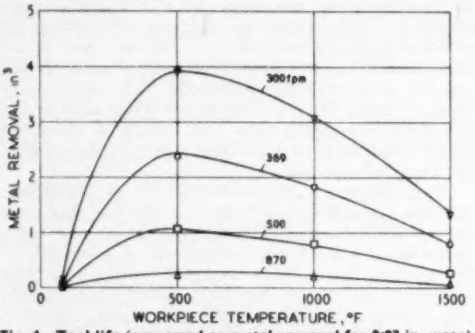

Fig. 4. Tool life (expressed as metal removal for 0·03 in. wear) as a function of workpiece temperature when face-milling Timken 16-25-6 alloy.

tool life at the lower cutting speeds. This is basically due to the fact that wear at higher speeds is by abrasion and increases with increased cutting speed, whereas wear at low speeds is caused by crumbling of the cutting edge and this gets worse as the speed is reduced.

Several curves were shown by Krabacher and Merchant for face-milling, but the more recent Air Materiel Command Project[6] included both turning and drilling life tests as well. The effects of increasing the workpiece temperature may be judged from Fig. 5, which pertains to an induction-heated workpiece of AM–350 stainless steel turned with a carbide tool at a depth of cut of 0·1 in. and a feed rate of 0·008 ipr. This particular graph has been chosen here because the increases in tool life, though worthwhile, are not over-dramatic and do not lead to the temptation to think of hot-machining as a panacea for all the troubles of high-temperature alloys. The increases in the case of the AISI 4340 alloy were, indeed, much more spectacular, a twenty-fold increase in tool-life being achieved by raising the workpiece temperature from ambient to 900°F.

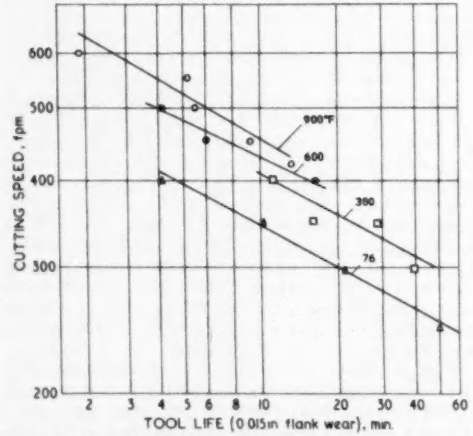

Fig. 5. Tool life as a function of cutting speed at various workpiece temperatures, when turning AM-350 stainless steel with a Carboloy-350 tool.

Tool life when face-milling 17-4-Mo alloy was increased a hundred-fold at a workpiece temperature of 1000°F but, in general, two factors other than cutting speed were found to influence tool life in face-milling, i.e., the initial angle of engagement between the tool and workpiece, and the presence or absence of a pad of asbestos on the engagement side of the workpiece. The first of these factors is governed by the offset of the cutter axis and the cutter diameter, and has been discussed at some length by Kronenberg[11]. The presence of the asbestos pad is thought to improve tool life by virtue of its damping characteristic (reducing the severity of impact) and the thermal insulation which it provides (thus maintaining the workpiece temperature at the point where the shock of impact takes place). After machining, Pentland found traces of some chemical constituents of the asbestos in the milling-cutter tips, and this led him to suggest a third effect, i.e., a chemical reaction, but it is not clear how this could affect tool life unless the products of the reaction were in some way of a lubricative nature.

In general, it would appear that there is a limiting workpiece temperature in milling, beyond which welding between the chip and tool tip occurs. This temperature is of the order of 1100°F and, if the workpiece is heated to a higher temperature, tool life falls markedly.

Pentland's results in drilling tests were variable. With high-speed-steel drills, the performance when drilling AISI 4340 was no better at 300°F than at room temperature, but a three-fold increase in tool life was obtained when drilling AM-350 stainless steel at 300°F. Carbide drills were used with AISI 4340 only and, with this material, no improvement in tool life was obtained.

Other Considerations

It will be clear that there are metallurgical questions in connection with hot-machining, such as possible changes in microstructure, tempering, etc. The recent Cincinnati investigations included metallographic studies in which samples were taken from the hot-machining surface and at a point 4½ in. distant. Comparison of these pairs of samples showed no change in microstructure, but hardness plots indicated that some tempering had taken place in some of the alloys which were more susceptible to thermal damage.

Specimens were heated by induction and by radio-frequency resistance methods and it was found that, while induction heating gave rise to tempering to a depth of about 2½ in., the radio-frequency resistance-heated specimens were tempered to a depth of only 1 in.

Appreciable workpiece distortion can be introduced by hot-machining techniques unless special care is taken. As with the problem of tempering, the main requirement is to produce a high concentration of heat in the volume which needs heating, and this will depend on the method of heating used.

Methods of Heating

Naturally, any method of heating should be as cheap as possible but, from a technological point of view, the method of heating need raise the temperature of the material in the shear zone only, and the heating of any other material may be regarded as indicative of loss of efficiency. It will be evident that no method of heating will be 100% efficient (judged by this criterion), but various methods can be examined in the light of this ideal and their efficiency weighed against cost and any other features which may be advantageous or disadvantageous. The principal methods of heating used industrially are as follows:—

(1) *Heating in a Furnace:*—In this case, the whole of the workpiece is heated and, on the score of efficiency alone, is not attractive. A simple variant of this principle

(which does not justify being classified separately) is resistance heating in which the electric current can be passed through the workpiece itself or through resistances placed in the fixture, temperature control during machining being effected, if desired, by thermostats.

(2) *Flame Heating*:—This is probably the oldest heating method for hot-machining purposes and has varied from a simple welding torch to special multi-flame fixtures specially developed for hot-machining. Apart from the difficulty of localizing heat, there is the possibility of damaging the newly machined surface.

(3) *Electric-Arc Heating*:—In this basically simple and inexpensive method, an arc is struck between a carbon or tungsten electrode and a point on the workpiece just in front of the tool. In order to control the arc, however, it may be necessary to use a magnetic field to prevent wandering of the arc, and to superimpose a high-frequency voltage to inhibit arc extinction. The electric arc has the advantage of good concentration of heat, but has the drawback of difficulty in achieving constancy of temperature. Also, the need for the operator to wear a welding-hood and other protective clothing restricts his ease of movement.

(4) *Induction Heating*:—This is another method which was used in the early days of hot-machining and is still very popular. It consists of passing an alternating current through a coil located alongside or around the workpiece, which thus becomes the secondary winding of a rather crude transformer. The voltage induced in the workpiece is dependent on its permeability, and the resulting current on its resistivity. Permeability is particularly important, since many magnetic materials effectively lose their permeability at temperatures above the Curie point (1400°F for pure iron). The heat is concentrated in a surface layer of a few thousandths of an inch, but localizing the area is more difficult.

(5) *Radio-Frequency Heating*:—This method was developed by Cincinnati in the course of the A.M.C. Project. Initially, two electrodes were used to lead the radio-frequency current into and out of the workpiece, using an air pressure of about 15 psi to prevent arcing. However, it was later felt that it would come closer to the ideal of heating the shear zone only if the current were led via a copper-plated chip-breaker to the chip and thence to the work (electrically insulated from the machine). Some very good results have been reported[6], but the leads to the electrodes need critical placing and there is a tendency for the tool-holder and tool-post to be heated by both parasitic induction and conduction. The idea however, is sound, and present development work is largely directed towards making the method work under workshop, rather than laboratory conditions.

(6) *Plasma-Arc Heating*:—Work has been proceeding at Cincinnati on the use of the plasma arc for heating non-magnetic materials. There are many difficulties to be overcome, but encouragement can be taken from the very rapid strides made in transferring plasma-arc welding from a specialized laboratory technique into a practical method of welding.

At this stage of development, it is impossible to be dogmatic about which heating method is best, but induction heating and radio-frequency heating seem to offer the greatest potentialities for, say, the next five years.

Conclusions

It is clear from the foregoing survey that the hot-machining of high-temperature alloys affords a considerable reduction in machining power and an increase in tool life varying by a factor of from 5 to 100, depending on the material and the machining process.

A good surface finish can be obtained, but the difficulty of accurately allowing for cooling contractions in all but the coarsest-tolerance work tends to limit the method to roughing operations. There appears to be little or no effect on microstructure, but some tempering may occur.

Acknowledgements

The author would like to thank Dr. M. E. Merchant for so readily placing at his disposal details of the research undertaken by the Cincinnati Milling Machine Company, from whose reports Figs. 3, 4, and 5 have been reproduced.

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A New Test Method for Determining the Spinnability of Metals

(*Concluded from page 82*)

recommended that further spinnability studies be carried out with temperature as a variable.

From the results of these tests, it is concluded that the ellipsoidal mandrel can be used to test the spinnability of materials, and that the spinnability of most materials can be predicted from the tensile-test reduction of area. The average percentage elongation cannot be used by itself to estimate spinnability.

It is also concluded that greater deformation is possible when spinning to a thickness less than that required by the sine law, and less deformation is possible with a thickness greater than sine-law thickness. Greater reductions should be possible in the spinning of cones if a round-nosed mandrel is used and the thickness on this nose is controlled to obey the sine-law at each point. This will eliminate bending and sudden changes in section, which may be detrimental to the operation.

Fabrication Studies of Columbium-Alloy Sheet

By A. F. TRABOLD and S. BANK

From *Metal Progress*, U.S.A.,
Vol. 79, No. 5, May 1961,
pp. 103–107, 9 illustrations.

A NEW du Pont columbium-base alloy designated D-31, which is being considered in the U.S.A. as a suitable material for re-entry space vehicles, has moderate high-temperature strength, compared with that of other columbium-base alloys, and possesses relatively good resistance to high-temperature oxidation and to oxide contamination. This alloy nominally contains 10% molybdenum, 10% titanium, 0·006% carbon, 0·05% oxygen, 0·007% nitrogen, and 0·0002% hydrogen.

The leading edges of space vehicles under consideration by the Grumman Aircraft Engineering Corporation will probably be of the built-up corrugated type and, to accumulate manufacturing data required for fabricating a leading edge from D-31 sheet, preliminary tests have been carried out by the company in connection with the welding, dimpling, shearing, machining, bending and forming characteristics of this alloy. The tests were effected on cold-rolled and stress-relieved sheet, which has a tensile strength ranging from 113,000 psi (6 to 9% elongation) at room temperature to 55,000 psi at 1600°F and 10,000 psi at 2400°F. Complete recrystallization (1 hr at 2400°F) destroys the ductility of the material.

These tests, as described below, indicate that the weldability of D-31 sheet leaves much to be desired, that it can be dimpled at 500°F but not at room temperature, that it can be sheared successfully at room temperature, that its machining characteristics are similar to those of austenitic stainless steel, and that it has fair bendability and relatively good formability.

The major deterrent to successful welding is an embrittling precipitate which forms on the heat-affected zone. To prevent this formation, spot-welding and electron-beam-welding techniques, which minimize the heat-affected zone, were evaluated. For spot-welding, a short-time, low-heat cycle was used. X-ray analysis and metallographic examination of welded samples revealed cracks extending through the material and running at 45 deg. to the rolling direction. A typical micrograph of a spot weld showed excessive electrode indentation and sheet separation, and an undersize weld nugget. Surrounding the as-cast nugget structure was a zone of partially recrystallized material which was very brittle. According to du Pont, it is possible to produce ductile, crack-free spot welds by keeping the weld cycle time as short as possible.

Electron-beam welding differs from ordinary fusion welding in that energy concentrations are exceedingly high, the weld cycle is completed in a short time, minimizing heat-affected areas, and welding is carried out in a vacuum chamber, eliminating atmospheric contamination. Two small samples of D-31 sheet were welded with an electron-beam machine, using a current of 100 kV, 2·5 mA and a feed of 30 ipm. A microsection of the surface of the weld showed recrystallization, incomplete penetration, undercutting, and porosity. Tensile and bend tests revealed the weld to be extremely brittle and low in strength. Failure occurred through the welded section, which had numerous cracks.

In missile and aircraft construction, thin fairing surfaces (skins) are connected to support members by rivets, and it is important that the rivet heads are flush with the skin surface to minimize turbulence. Since skins are made of thin-gauge sheet, countersinking is not possible and recessions or dimples must be made instead. Dimpling tests were performed at room temperature, and also at elevated temperatures (500 to 625°F), using a hot pressure pad. All dimples produced at elevated temperatures were satisfactory and showed no evidence of cracking by X-ray and metallographic examination. All dimples produced at room temperature exhibited cracks running at 45 deg. to the rolling direction, similar to those on the spot-welded samples.

Any attempt to explain this apparent plane of weakness must assume that the behaviour of columbium alloys is similar to that of other body-centred cubic materials when rolled. The crystal orientation in D-31 sheet after rolling would be one in which the (001) planes would lie essentially in the plane of the rolled sheet, with the (110) directions of the grains lying in the direction of rolling. This orientation places the cube faces (100) at 45 deg. to the rolling direction. Fracture of this material might then occur on cleavage planes, if the alloy is sensitive to cleavage failure.

According to du Pont, 45-deg. brittleness may be minimized by using sheet with an interstitial content below 550 ppm and nitrogen below 80 ppm (the interstitial content of the sheet for this evaluation was 920 ppm, and the nitrogen content was 102 ppm) and by keeping interstitial contamination low by preventing oxygen, nitrogen, and hydrogen from diffusing into the sheet during high-temperature treatments. In D-31 sheets with a high interstitial content, dimples can be successfully produced by increasing the forming temperature to between 500 and 625°F.

To determine the shearing characteristics of the sheet, a specimen was sheared with a blade-gap setting of 0·002 in., as commonly used for cutting stainless-steel sheet. Die-penetrant inspection indicated the presence of "cracks" on the sheared edge, and metallographic examination showed these indications to be an unusual serrated edge on the sheared surface. Although D-31 sheet can be sheared successfully at room temperature using a 0·002-in. gap setting, better edges may be obtained with other settings. However, if the material is sheared as described above, deburring to a depth of at least 0·002 in., in order to remove the serrated edge, is recommended.

Insofar as machinability is concerned, drilling and milling (profile) characteristics were determined, using a standard drill press with a force-gauge attachment and a standard milling machine. Dry, hand-feed techniques and a 135-deg. split-point, No. 18 Morse drill were used to make holes in 0·040-in. sheet. At 18 sfpm, an average of 72 lb thrust was developed, and an exit burr of 0·008 in. and a 0·003-in. wear-land on the cutting lip after drilling 15 holes were produced. At 33 sfpm, an average of 62 lb thrust was developed, and an exit burr of 0·010 in. and a 0·006-in. wear-land on the cutting lip after drilling 15 holes were obtained.

For end-milling tests, a 1¾-in. diameter, 6-flute, right-spiral, right-hand cut, high-speed steel cutter was used. Speeds varied from 32 to 700 sfpm at 0·0005 to 0·007-in. chip loads (depth of cut per flute). Speeds of 32 to 92 sfpm at 0·005 to 0·002-in. chip loads gave the best

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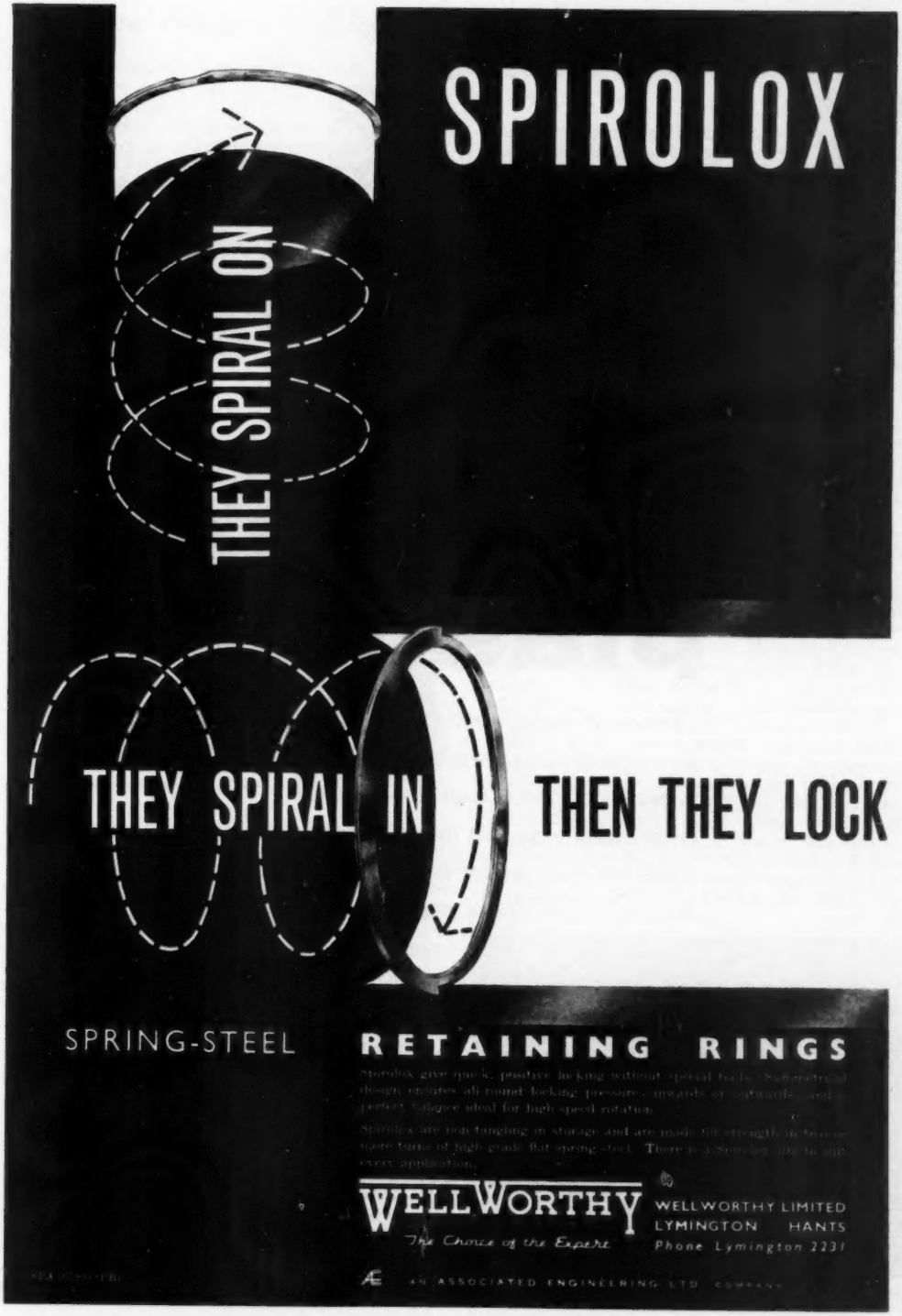
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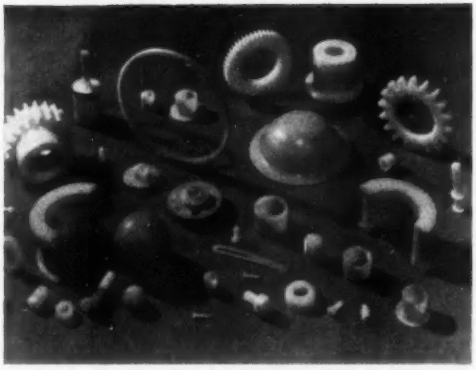
The Scope of Plastics in Engineering Design

By V. E. YARSLEY, M.Sc., D.Sc.(TECH.), F.R.I.C., F.P.I., W. FLAVELL, B.Sc., A.R.I.C., and L. W. TURNER, B.Sc., A.R.I.C., A.P.I.

THE first plastics material was produced in England almost a century ago by Parkes, who developed celluloid —a compound based on cellulose nitrate plasticized with camphor—primarily to simulate such materials as ivory and tortoise-shell. Some time later, Hyatt perfected this material in the U.S.A. to win a prize offered for the production of synthetic (xylonite) billiard-balls. Quite early in the present century, the aesthetic properties of celluloid were applied to the production of semi-utilitarian goods, and were extended to decorative articles as a result of the introduction of coloured celluloid. Quite apart from its decorative uses, celluloid was, and still is, a useful material in other fields. Indeed, its use as a flexible carrier for photographic emulsions, in place of glass plates, did much to simplify the design of cameras and speeded up the development of motion pictures.



A selection of machined parts made from Polypenco Nylon 66. *(Courtesy of Polypenco Ltd.)*

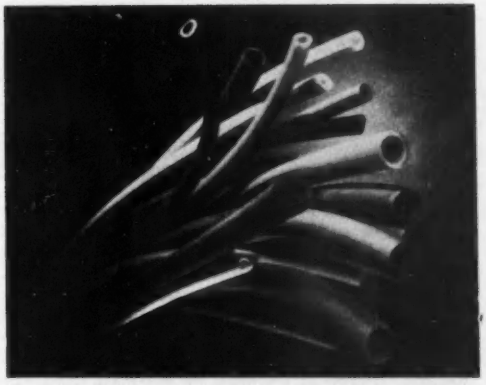
The changes in chemical thinking which followed the epoch-making research of Baekeland, culminating in the development of the phenol formaldehyde resin now known as Bakelite, and later the advent of the urea formaldehyde plastics, were accompanied by radical changes in the approach to these so-called synthetic materials. Whilst the clear family relationship between these and the cellulose-based products was for long not appreciated, it was nevertheless apparent that these remarkable solids, which resulted quite surprisingly from the reaction of liquids in a test-tube, merited intensive investigation. Real progress was made in this direction in the early 1930's when the du Pont laboratories in the U.S.A. built up a synthetic material structurally similar to natural silk. The material now known as nylon resulted from this work and realized the early dream of Carleton Ellis that plastics could be tailored at will.

Advances in the direction of this molecule building made just prior to World War II resulted in the commercial production of a number of plastics, notably polyvinyl chloride (P.V.C.), polyethylene (polythene) and polystyrene, all of which were destined to play a significant part in the war. The hard testing of war-time applications established plastics as engineering materials to such an extent that it is fairly safe to say that, insofar as their development is concerned, they emerged from the war several decades ahead of their entry.

As a result of the intensified research effort during the past fifteen years, some entirely new plastics have emerged, but, in the main, the advance has centred on the accurate building up of the plastics structures in what is now referred to as a stereo-regulated or stereo-specific pattern. Considerable development effort has also centred in producing the essential raw materials for plastics, many of which are obtained from the breaking down or cracking of oil. Thus, concurrent with the growth of plastics in the post-war years, has come the establishment of vast chemical-producing industries based on oil (the so-called petrochemical industries), which are now a significant part of the chemical industry in every major country.

One thing is certain:—As a class of structural materials, plastics have, in their relatively short lifetime of little more than a few decades, effected radical changes in the design of many everyday articles and, in addition, have made it possible to produce designs which, were it not for plastics, could never have been conceived at all.

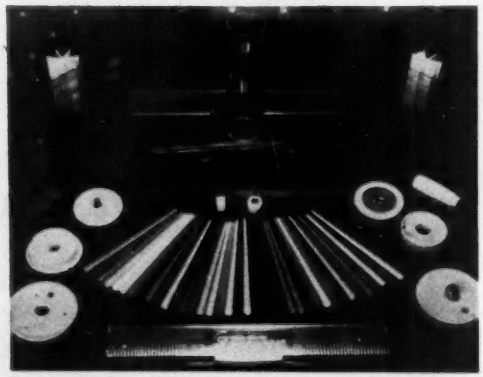
The ability of plastics to function as engineering materials stems from the nature of their molecular structure. By contrast with metals and the simple inorganic chemicals of everyday life, such as common salt or washing soda, all of which have precise and compact molecules, plastics are materials with giant molecules disposed in long chains. The properties of the end-product are governed both by the length and regularity of the chain, as also by the nature of the constituent units. The analogy of this chemical chain building with the hay-band used by farmers for binding will be clear when it is considered that, to produce a good strong band, the farmer selects for his use the largest hay strands; he could never produce a hay-band from short-fibre grass. Equally, when chemical chains are constituted of simple hydrocarbon units, products are obtained of increased elasticity, compared with those in which the constituent units are bulky and/or complex. Variation of the size and type of the molecular chain gives materials ranging from rubber-like solids to those having



Examples of tubing made from highly elastic polyvinyl chloride. *(Courtesy of Portland Plastics Ltd.)*

hard, brittle, glass-like properties. Herein lies much of the industrial importance of plastics. By controlled variation of the molecular structure, either by direct chemical synthesis of suitable long-chain structures, or by the addition of modifying materials to extend existing natural long-chain structures, such as those based on cellulose or natural resins, materials can be produced which have indeed only one serious limitation, namely that, as they are organic (i.e., carbon-based materials), their heat resistance is limited to what the carbon-to-carbon or carbon/hydrogen bond will stand. Even this defect is now being overcome in the organo-metallic or completely inorganic complexes which are being developed.

Early in the development of plastics it was found that they are poor conductors of heat and electricity, and that they have considerable resistance to corrosion; indeed, such were the remarkable electrical properties of the synthetics, that the electrical companies themselves did much to sponsor their early manufacture and development. The part played in this early development by gutta-percha is often overlooked, but it is interesting to note that, after over a century of use, it still holds its own for certain specific applications. As the new materials became available in improved quality and quantity, the electrical industry in particular showed that they could be used with advantage, so much so that the development of plastics in electrical engineering provides one of the finest examples of the use of plastics, as much for their physical as for their functional possibilities. One by one, articles in the then very limited range of electrical equipment changed their outward form as the use of plastics extended, the change usually following the substitution of a relatively small moulded unit for the relatively large and often quite ornate porcelain or metal prototype. This was perhaps most noticeable in England in the early thirties, when the ungainly upright telephone gave place to the hand-microphone type, which has suffered little further change in twenty years.



Parts made from "Diakon" acrylic polymer, as used in the manufacture of Gestetner duplicators and accessories.
(Courtesy of Imperial Chemicals Industries Ltd.)

The change was more subtle than most users then or even to-day appreciated. It was not only that the end-products in themselves were more functionally designed, which they most certainly were, but the actual process of forming them by compression or injection moulding was equally so. The units of the new age were produced by methods attuned to the needs of something until then relatively unknown—mass production. About the time of this advent of the streamlined hand-microphone telephone came appreciation of the potentialities of plastics in the electrical industry generally, and the realization of the production advantages of repetition moulding. It is difficult to-day to appreciate just how limited this realization was at the time, but early text-books dealing with injection moulding, for example, refer to this method as admirable for the production of small units weighing but a few grams, such as screw tops for toothpaste tubes.

It is indeed a far cry from the early injection machines of Shaw or Eckert and Ziegler to the current 200-oz giants of Windsor, Peco, or Battenburg, capable of producing 90-oz polyethylene waste-bins in a three-minute cycle. The advent of the hand-microphone telephone is but one of many examples which could be selected to show the subtle changes which have taken place. It is interesting to note that this industry was the centre of another remarkable change, just over a year ago, when the British Post-Office authorities decided to abandon the long-service Bakelite type of compression-moulded hand-microphone in favour of the injection-moulded unit in colourful thermoplastic methyl methacrylate ("Diakon")—a material and process change of considerable significance to the plastics industry in this country.

Outwardly, as the years have gone by, a number of well-known articles of everyday life have taken on a new and more attractive appearance; in actual fact, the change has been much more fundamental and significant, since it has been as much a revolution in materials and processes as it has in outward appearance and design. Initially, many of these attractive changes, together with many quite novel productions of entirely new units, were concentrated in one or other of the many branches of the electrical industry for the obvious reasons that, in addition to combining strength with lightness, plastics offered excellent electrical insulation. This outstanding advantage more than offset the inborn prejudice which almost every engineer felt initially against the new synthetic materials. Other branches of engineering were less fortunate in their forthright approach to the use of the new materials, so that the progress of plastics in many of these was for a long time less rapid.

The automobile and aircraft industries, which had grown up contemporary with plastics, had fewer inborn prejudices, so that they were more inclined to give the new materials a chance to show what they could do. The initial demands of the aircraft industry appeared to exceed the potentialities of plastics, but gradually, and often in unexpected ways, the new materials became co-functional with the old materials to yield aircraft of superior design and performance. In this connection, it would be difficult to assess what aircraft design owes to the availability of "Perspex", which has made streamlined visibility a reality, or to the synthetic adhesives, which made possible the production of the "Mosquito" aircraft.

Classification of Plastics

As already indicated, plastics are chemicals which are built up unit-wise into long and frequently complex bundles of chains. The single units or bricks are styled monomers, while the finished plastics chain is referred to as a polymer and the process of building up the monomer into the finished polymer is termed polymerization.

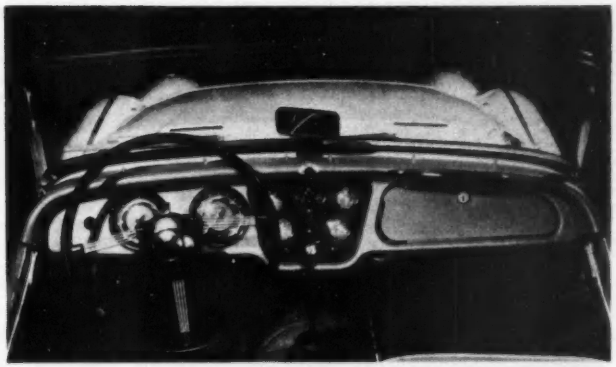
All plastics fall into two broad families. Those in which the long chains slip freely over one another under

the action of heat and suffer no inter-chain chemical change are called thermoplastic. Those, by contrast, which undergo a chemical change in which the chains are cross-linked one to the other, so that they are incapable of relative motion under the action of heat, are designated thermosetting. To-day, the distinction between the two families is much less definite than it was a decade or so ago, since it is now a relatively easy matter to cross-link the chains of traditionally thermoplastic materials by the application of high-energy radiation, and so render them infusible and thus thermosetting.

Plastics were at one time mainly worked in the form of powders by processes of injection or compression moulding, but to-day the centre of gravity of the industry is moving further and further away from the moulding shop. Plastics are now widely applied in the form of sheets, rods, and tubes, very much in the manner of traditional materials. Here, of course, in the case of the thermoplastic materials, advantage is taken of the fact that the material is readily thermoformable in such processes as vacuum (or suction) forming and extrusion blowing.

Plastics are also widely available in forms in which they are perhaps not so readily recognized as such, i.e., reinforced with fibrous materials, or combined with sheets of metal, wood, paper, or fabric in the form of laminates. Modern laminated plastics offer a wide variety of materials to the constructional engineer, in many cases combining the outstanding properties of both the plastics and traditional components. An excellent example of this is steel sheet coated with polyvinyl chloride, marketed under the trade name of "Stelvetite", which has structural and decorative functions and, at the same time, avoids the corrosion dangers to which sheet metal is subject.

Also in this category come the plastics reinforced with metal or with glass or natural fibres, or, as more usually stated, fibres bonded with suitable plastics to give structural sheets, rods, or tubes. Nowadays, it is not uncommon to hear such materials referred to as polyester/glass, or merely (quite incorrectly) as fibre-glass. It is not surprising that many people who have only heard the material thus designated fail to appreciate that it is one of the many forms in which plastics are available to industry.



The Stelvetite fascia panel of the "Triumph" T.R.3 sports-car.
(Courtesy of John Summers & Sons Ltd).

New Plastics Materials

For reasons of space limitation, it is not possible to include in this article descriptions of the older and well-established plastics materials, such as those to which reference has already been made. However, for the sake of interest, brief details are given in the following of some of the newer elastomeric, thermoplastic, and thermosetting materials.

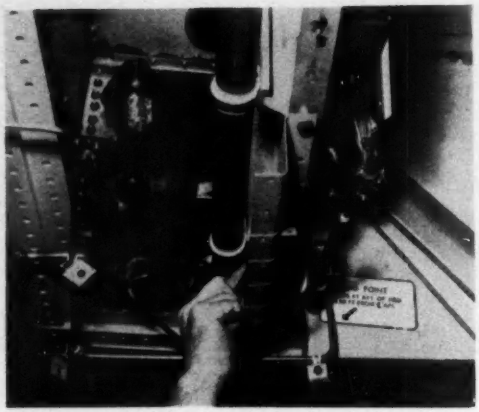
Elastomers

"*Viton A*":—This is an elastomeric, i.e., a rubber-like, material developed in the U.S.A. by E. I. du Pont de Nemours & Co. Chemically, it is a copolymer of vinylidene fluoride and perfluoropropylene, and is characterized by its very wide range of working temperature, i.e., −40°C to +260°C. Viton A also has very good resistance to oils, lubricants, fuels, hydraulic fluids, and solvents in general, being swollen only by highly polar solvents, such as acetone or dimethyl formamide, and it stands up well to weathering and to oxidizing agents, including ozone. This combination of properties serves to make Viton A of particular interest in aircraft applications in the form of gaskets, tubing, etc. At present, its high price precludes it from application in a wider field. An improved version of Viton A, having even better thermal stability and fluid resistance, is now available under the name of Viton B.

"*Kel-F*" *Elastomer*:—This elastomer, developed in the U.S.A. by the Minnesota Mining and Manufacturing Company, is a fluorinated material related to Viton A, being a copolymer of vinylidene fluoride and chlorotrifluoroethylene. Its properties and applications are also similar to those of Viton A, but with a somewhat lower maximum service temperature. The tensile strength of Kel-F elastomer, on the other hand, is appreciably higher than that of Viton A, and it is also easier to vulcanize.

Dihydroperfluorobutyl Acrylate (*F.B.A. Fluoro-Rubber IF 4*):—This material represents another attempt to use the exceptional chemical-resistance properties of the fluorinated alkanes in the formulation of high-duty rubbers. In this case, the backbone of the polymer consists of a hydrocarbon chain, and this is reflected in lower thermal stability, as compared with the Vitons and the Kel-F elastomer. The properties of F.B.A. depend to some extent on the method of vulcanizing, but in general it has a rather low tensile strength, good resistance to ozone and weathering, and fair resistance to fuels and solvents. It is attacked by oxidizing acids and by alkalis. Its maximum service temperature is around 200°C.

Perfluoronitroso Elastomers:—A new series of elastomeric compounds has been developed in the U.K. by Professor Haszeldine at Manchester. These compounds are derived from the copolymerization of trifluoronitrosomethane and tetrafluoroethylene and therefore contain nitrogen and oxygen atoms in the polymer chain. These elastomers retain their flexibility at temperatures down to −30°C and have excellent resistance to solvents. Their tensile strength is rather low, however, and the upper limit of service temperature appears to be about 180°C. These materials are still in the development stage, and



Fabric coated with "Viton" synthetic rubber for fire-wall seals in supersonic jet aircraft.
(Courtesy of du Pont Co. (United Kingdom) Ltd).

improvements in those properties which are at present deficient can be expected.

Ethylene-Propylene Rubber (C23):—This rubbery copolymer of ethylene and propylene has been developed in Italy by Montecatini, using specially devised catalyst systems of the organo-metallic type. Potentially, this C23 rubber can be extremely cheap, since the two monomers (ethylene and propylene) are amongst the cheapest of currently available raw materials. C23 is completely saturated and therefore requires special vulcanization techniques. Its saturated character, however, gives it outstanding resistance to ageing and to such degrading agents as heat, oxygen, ozone, and ultraviolet light. Another interesting property is the very low specific gravity (0·85) of the uncompounded rubber—a feature which reduces the cost of articles on a volume basis. The mechanical properties of C23 rubber are intermediate between those of natural rubber and the butadiene-styrene synthetics. It can thus be regarded as a general-purpose rubber with particularly good ageing properties. Applicational tests have been carried out using C23 in car-tyre treads, conveyor belting, cables, and flooring.

Cis 1 : 4 Polybutadiene:—This material has recently been introduced on the market in both America and Russia, and stems from the intensive research which has been carried out on stereo-specific polymerization, using metallic or organo-metallic catalysts. Polybutadiene has excellent elastomeric properties which are retained down to −80°C. In this respect, it is therefore superior to both natural rubber and "synthetic" natural rubber (cis polyisoprene). Its tensile strength is somewhat lower than that of natural rubber at room temperature but better at 100°C, and it has a higher resilience than natural rubber. Polybutadiene is potentially a cheap material, which can be regarded as a general-purpose rubber with applications similar to those of natural rubber, though its greatest outlet will probably be in the form of blends, either with natural rubber or with polyisoprene. Polybutadiene itself is rather difficult to process on the mill, except within a rather narrow temperature range, but these difficulties are not apparent in the case of blends.

Synthetic Natural Rubber (Cis 1 : 4 Polyisoprene):—It has been the aim of polymer chemists for many years to produce a synthetic rubber having the same molecular structure as natural rubber. This aim has now been achieved by the polymerization of isoprene, using organo-metallic catalysts. This synthetic natural rubber is very similar in its properties to natural rubber, as would be expected. Its tensile strength is a little lower but, on the other hand, its thermal stability and resistance to ageing are rather better. Tests on truck tyres carried out in America have shown that the synthetic material has a better tread-crack resistance than natural rubber, and a tread wear of about 85% of the natural material.

Polyurethanes:—In the strict sense, polyurethanes are not new materials, having been on the market for some ten years. However, the upsurge of interest in them over the last two or three years, combined with recent technical improvements in their composition and methods of processing, make them worthy of note. Polyurethane is a generic term covering a group of materials derived from the reaction between a polyhydric alcohol and a polyisocyanate. They are amongst the most versatile of plastics materials, being used as foams, both rigid and flexible, rubbers, adhesives, and surface coatings. Their biggest application at present is in the field of flexible foams for upholstery, where they are competing strongly with more traditional materials, such as rubberized hair and foamed latex. The rigid foams are being used as thermal insulants in refrigeration equipment, where they are particularly useful, as they can be formulated to have a thermal conductivity very much lower than competing materials, such as cork and expanded polystyrene.

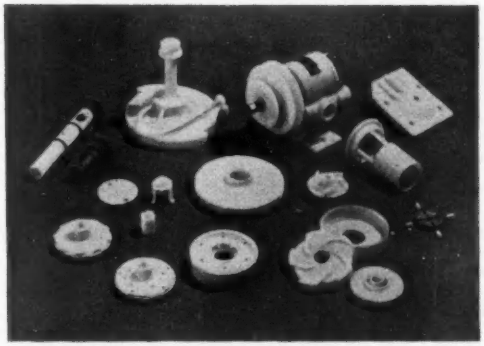
The rigid foams are also used in "sandwich" structures, which have a high rigidity combined with light weight. Such foams can be produced *in situ*, a liquid composition, introduced into the cavity to be filled, foaming spontaneously. Thus, this type of material can readily be used to fill cavities which are difficult of access. Solid (i.e., unfoamed) elastomeric polyurethanes are produced by a casting process, though attempts have been made to produce a gum stock which can be processed by conventional techniques. Polyurethane rubbers are characterized by exceptionally good resistance to tearing and to abrasion. In this respect, they are superior to all other rubbery materials currently available. They find application in pipe and pump linings, flap valves, etc., for handling abrasive slurries. They are resistant to most solvents and to dry heat, but tend to break down with wet heat.

Thermoplastic Materials

Polyformaldehyde:— Polyformaldehyde, sometimes called polyoxymethylene or acetal resin, represents the culmination of many years of research in the U.S.A. by E. I. du Pont de Nemours & Co. Polymers of formaldehyde have been known for many years and were the subject of important theoretical studies on the chain structure of polymers carried out by Staudinger in the 1920's, but had very poor thermal and hydrolytic stability and no commercial value as mouldable materials. du Pont, however, have discovered means of stabilizing polymers of formaldehyde, and have thereby obtained mouldable thermoplastics of outstanding properties.

"Delrin", the polyformaldehyde developed by du Pont, finds its applications primarily in engineering uses. It is a rigid, tough polymer but its toughness is more akin to the resilience of a steel spring than to the more rubbery

toughness of nylon or polyethylene. When slightly deformed by an applied load, it will recover almost completely as soon as the load is removed, making it suitable for use in snap-fit assemblies. Delrin has outstanding resistance to organic solvents at ordinary ambient temperatures. It is not recommended for use in contact with strong acids or alkalis, but withstands attack by solutions of neutral inorganic salts. It has a maximum continuous service temperature of about 85°C, but may be used intermittently at temperatures up to 120°C, depending on loading and environment, and retains its toughness and resilience down to temperatures around −40°C. Applications for polyformaldehyde include car handles, machine housings, valves, gears, pump impellers, rollers, hinges, etc.



A selection of components made from "Delrin" acetal resin. *(Courtesy of du Pont Co. (United Kingdom) Ltd.)*

Polycarbonates:—A new type of thermoplastic material, developed simultaneously in Germany by Farbenfabriken Bayer A.G. and in America by G.E.C., is derived from the condensation of diphenylol propane and phosgene or diphenyl carbonate. This material, known in Germany as "Makrolon" and in the U.S.A. as "Lexan", possesses a unique combination of mechanical and electrical properties. Its most characteristic feature is its extremely high impact strength, which it retains even at very low temperatures. It has a low water absorption, and therefore good dimensional stability, and a maximum service temperature of about 135°C. It is resistant to many oils and dilute acids, but is attacked by concentrated acids and by alkalis. Polycarbonates can be injection-moulded and extruded, using conventional machinery, and can be formed into tubes, sheets, and thin films. The main applications of polycarbonates are those which require a rigid material of good shock resistance and dimensional stability under conditions of changing humidity.

Chlorinated Polyethers:—A new type of polymer, having a polyether chain with chloromethyl sidechains, has been developed by the Hercules Powder Co. in the U.S.A., and is available in developmental quantities under the name of "Penton". Penton is a rigid thermoplastic which can be injection-moulded or extruded by conventional techniques. It is distinguished by its very low water absorption, which gives it excellent dimensional stability under humid conditions, and its retention of strength and dimensions at elevated temperatures. It is thus suitable for applications involving contact with boiling water or low-pressure steam. It has excellent resistance to a wide range of chemicals, both organic and inorganic, and has been suggested for use in valves, pumps, and pipes for handling chemicals. It is attacked by fuming sulphuric acid and fuming nitric acid.

Polyvinyl Fluoride—This material represents another development arising from the basic work on fluorine chemistry undertaken by the du Pont company in America. It is available as thin film, in which form it exhibits a combination of properties superior to all other films currently available. Its resistance to weathering is quite exceptional, and tests carried out in Florida showed very little change in elongation after seven years outdoor exposure; on the other hand, the life of films of polyvinyl chloride, polyethylene, and cellulosics, expressed on the same basis, was only a matter of months.

Polyvinyl fluoride is intrinsically a tough and flexible material, i.e., it does not require plasticizers to produce these properties. It retains its toughness and flexibility at very low temperatures (down to −180°C), and is still very strong at high temperatures. At +150°C it is stronger than polyethylene film at room temperature, and its zero-strength temperature is about 300°C. The permeability of polyvinyl fluoride film to gases is of the same order as that of polyester film; it transmits water vapour at about twice the rate of polyethylene film. Polyvinyl fluoride is substantially unaffected by solvents at ordinary temperatures, but is partially soluble in a few polar solvents at temperatures above 150°C. It is unaffected by boiling in strong acids and bases. In electrical properties, it has an unusually high dielectric constant (7·5), and a low loss factor (0·005 at 60 cps). The combination of properties possessed by polyvinyl fluoride film suggests its application as greenhouse and other horticultural glazing, as decorative and protective film for a variety of surfaces, in packaging, and in capacitors and cable construction. The price of polyvinyl fluoride is too high at present for widespread application, but with a fall in price its use could be expected to expand greatly.

Inorganic and Semi-Inorganic Polymers:—In recent years, the service temperature required from plastics materials has been raised to higher and higher levels, owing to the vastly increased interest in rocketry and space flight. As long as materials are based on a purely carbon backbone there will be limitations to the temperature which they will withstand. Attention has therefore increasingly turned towards polymers containing elements other than carbon in the main chain.

Intensive research is proceeding all over the world on the incorporation of metal atoms into plastics, but it is difficult to assess the current position, as the results and applications of such work are carefully guarded secrets. It is known, however, that Professor Andrianov in Russia has developed techniques for the production of resins based on silicon-oxygen-aluminium and aluminium-oxygen chains. Other elements, such as titanium, germanium, and zirconium, can also be incorporated. The structure of the main chains of such polymers thus approaches that of alumina or silica, which are known to have outstanding heat resistance. It is not known to what extent these materials have been utilized in Russian rocketry, but it has been reported that mouldings weighing several pounds were exhibited at the Leipzig exhibition in 1959.

Another approach to the incorporation of metallic atoms involves the so-called co-ordination polymers,

which comprise metal atoms linked by organic units, usually by both covalent and co-ordinate bonds. The bonding of the organic unit to the metal atom appears greatly to increase its stability to heat, a fact which has long been recognized for "monomeric" co-ordination compounds, such as copper phthalocyanine and beryllium acetyl acetonate. The main problem with co-ordination polymers at present is to devise methods of producing materials with a high degree of polymerization.

Considerable research is being devoted to the production of resins based on silicon, phosphorus, and boron. The silicon-oxygen backbone has been known for some years and forms the basis of the silicones, but now the silicon-nitrogen, silicon-boron, boron-nitrogen, boron-phosphorus, and phosphorus-nitrogen linkages and their various combinations with oxygen are being studied as a basis for polymer production. Much work has been published on resins and rubbers derived from polyphosphonitrile chloride. These are entirely inorganic in nature and have good heat resistance but, unfortunately, have only a poor resistance to hydrolysis.

It should perhaps be emphasised that the materials described above, with the exception of the phosphonitrile chloride polymers, are not yet articles of commerce. They are mentioned here as being indicative of the trend which plastics materials research is taking, and should be regarded as materials of the future, in some cases the distant future.

Thermosetting Materials

Alkyd Moulding Compounds:— These moulding compounds are based on polyester resins compounded with granular mineral fillers or with glass fibre. When warmed through, the material shows very free flow and rapid cure, without the elimination of volatiles. Moulding pressures can be of the order of 500 psi; the cure for thin sections can be 15 seconds. The chief applications of alkyds are in the electrical-components field, their tracking resistance being particularly good, while their heat resistance and dimensional stability are excellent.

Allyl Moulding Resins:—The main allyl-type moulding resins are prepolymers of diallyl phthalate (DAP) or diallyl isophthalate formulated with peroxide catalysts to cause polymerization under heat. Fillers are incorporated. The polymerization and cross-linking reactions proceed without volatile production, in contrast to phenolics or amino resins. The dimensional stability of allyl resins is of a high order, heat resistance is good (the diallyl isophthalate resins are outstanding in this respect), and chemical and water resistance are excellent. The material finds ready application in the electrical-components industry.

Epoxy Moulding Compounds:—These are rather new to British moulders but, as they have certain unique properties, increasing use can safely be predicted, despite slower cure in present formulations. Epoxy moulding compounds can be employed for compression and transfer moulding, the conditions depending on the type and proportion of filler incorporated. Fillers can be mineral, e.g., clay, mica, silica or even graphite in powdered form, or they can be fibrous, e.g., glass or synthetic fibres. Some of the advantages claimed for the epoxy moulding compounds are superior dimensional stability; extremely low moulding pressure, permitting the use of delicate inserts and thin-section moulding; retention of electrical and mechanical properties, and resistance to alkalis.

Some of the properties of glass-fibre-filled alkyd, allyl, and epoxy moulding compounds, compared with those of glass-fibre-filled melamine and phenolic compounds, are shown in Table I.

Engineering Features of Plastics Materials

General Properties

It is fairly safe to say that, with the possible exception of resistance to excessive heat or open flame, one or other of the commercial plastics can meet most reasonable needs of the engineer. This must not be interpreted as saying that plastics equal metals in all their physical properties—most certainly they do not. It does mean, however, that, suitably selected according to application and possibly combined with traditional materials in exceptional cases, plastics can give the engineer materials to meet a surprising percentage of his overall needs, subject to the reservations already made. What is not quite so easy to answer is whether or not plastics can at all times meet the needs as economically as can the traditional materials. In deciding what plastics can meet his need, the engineer must review a number of general physical properties, some of which are covered in the following:—

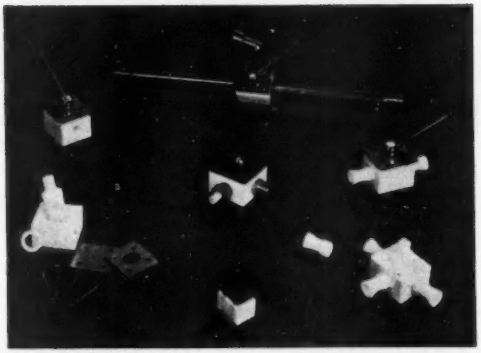
Heat Resistance:—Apart from the specially compounded heat-resistant materials, most currently commercial plastics are carbon compounds and, as such, have temperature limitations which vary according to the constituent elements and the energy values of the bonds joining them. Such is the current knowledge of the kinetics of depolymerization (as of polymerization) that these can be calculated, so that, at the upper end of the thermal scale, the engineer can be told exactly how a given plastics material will perform, when it will soften freely or under load, and when, if further heated, it will ultimately collapse or decompose. If actual resistance

TABLE I: PROPERTIES OF SOME THERMOSETTING MOULDING COMPOUNDS WITH GLASS-FIBRE FILLERS

	Melamine Formaldehyde	Phenol Formaldehyde	Diallyl Phthallate	Alkyd	Epoxy
Compression moulding temperature [°F]	280–340	280–350	270–320	280–350	280–310
Compression moulding pressure [psi]	3,000–6,000	1,000–5,000	500–2,000	500–2,000	100–2,000
Specific gravity	1·9–2·0	1·75–1·95	1·55–1·68	1·8–2·3	1·6–1·9
Tensile strength (ASTM D638, 651) [psi]	6,000–10,000	5,000–10,000	6,500–7,000	4,000–10,000	5,000–7,000
Continuous resistance to heat [°F]	300–400	350–450	400–450	300–350	300–400
Water absorption [%], 24 hr, ¼-in. thickness	0·3–0·6	0·1–1·2	0·12–0·35	0·06–0·28	0·1

to burning is required (which, be it noted, is styled non-inflammability in this country, but inflammability in the U.S.A. and by the British Plastics Federation rating), then, by the incorporation into the plastics chain of a halogen atom or atoms or by the addition of flame-retarding agents, such as antimony salts, the desired property can usually be attained.

It must not be forgotten that considerable improvement in the thermal resistance of a polymer can often be effected by increasing the regularity of its molecular structure. This has been demonstrated recently by Professor Natta with his stereo-regulated polymers, in which the substituent groups are aligned on one side of the main carbon chain, in what he styles the isotactic arrangement. In this way it is claimed to be able to produce isotactic polystyrene, which softens at 230°C, as compared with just around 100°C for the ordinary commercial grade.



The use of "Fluon" P.T.F.E. in the construction of the Watson-Marlow "Omega" valve.
(Courtesy of Imperial Chemical Industries Ltd.)

It is not so easy to cater for the other end of the thermal scale, and many plastics are quite unsatisfactory or definitely suspect at ultra-low temperatures, down to, say, −50°C. Here, there is very little that can be done, and a plastics material either will or will not continue to function at such low temperatures. Selectivity can only be applied as between the likely members of a few plastics families, of which the most likely to be of interest to the refrigeration engineer are the halogenated hydrocarbon polymers, polytetrafluoroethylene (P.T.F.E.) and polychlorotrifluoroethylene (P.C.T.F.E.), etc. In the case of the more common vinyl polymers, such as polyvinyl chloride (P.V.C.), the addition of suitable plasticizers can effect considerable improvement, sufficient indeed to meet most commercial needs.

Heat Transfer:—Plastics are outstanding among constructional materials for their low heat conductivity. In this respect, plastics contrast with metals, and for this reason they find application in competition with metals in cases where what may be termed "touch comfort" comes in question. Handles for tools and machines are prepared in plastics because operators find them more pleasant to use. Plastics table tops for domestic and commercial use are preferable to metal, glass, or marble for a similar reason. On the other hand, the fact that plastics cups give less temperature contrast to the lips than china or porcelain has militated against the use of plastics in this sphere, though they are used in canteens on account of their greater durability and chip resistance.

Tensile Properties:—There are possibly few more vexed questions connected with plastics than those associated with tensile strength, toughness, and stiffness. Whilst much of the old prejudice has been lived down, there are still engineers who associate strength of materials with their weight and cannot appreciate that, as far as specific strength is concerned, plastics are actually superior to many of the conventional materials. Nevertheless, these are points to which the plastics industry is constantly directing its research effort, though it must be emphasised that careful and critical selection must be made, taking into account the overall functional conditions the materials will have to meet. In particular, if thermoplastic materials are to be used, care should be taken that the necessary tensile properties will be maintained through the whole temperature range of the expected working life of the product.

Where there may be some doubt that available plastics cannot meet projected needs, the possibility of using reinforced plastics should be considered. To-day, a large number of standard laminated and reinforced materials are offered as sheet, rod, or tube, and special needs can usually be met by products tailored to the job. In this connection, the possibility of epoxy- or polyester-bonded glass-fibres or metal-reinforced plastics should always be considered where difficult strength requirements have to be met. The aircraft industry long ago demonstrated what can be done in this direction and some of their pioneer efforts, such as the reinforcement of plastics with punched metal, have stood the test of time.

Corrosion Resistance:—In broad terms, plastics can be recommended as materials of superior corrosion resistance but, quite obviously, when selecting a plastic for a specific use, due attention must be paid to the type of corrosion involved. In this respect it is difficult to lay down hard-and-fast rules, and in every case ambient conditions must be taken into account. Whenever possible, before any application is attempted where unknown or suspect conditions are likely to be encountered, users should consult the manufacturers of the likely plastics they select, and, if possible, the projected application should be simulated with accelerated ageing tests. It is in respect of endurance tests that plastics compare unfavourably with metals, for which data have been collected in some cases for more than a hundred years.

Because of their corrosion resistance, plastics are being utilized even more widely to-day as coatings for metals. As has already been mentioned, commercial laminates of mild steel and polyvinyl chloride are now available and these are being used for a variety of decorative and structural purposes, particularly when corrosive conditions are likely to be encountered.

Colour:—In the earlier days of their history, plastics made their mark for their colour potentialities and, as the years have gone by, the demand for plastics as a colour medium for both domestic and industrial applications has increased. Considerable research has gone into this branch of the industry, and fast colours are now available for most types of plastics for almost any possible application. Here again, it is wise to consult manufacturers of both plastics and dyestuffs before difficult applications are attempted, and it must be remembered as quite axiomatic that a dyestuff or pigment which is quite satisfactory for one plastic will not necessarily be satisfactory for another, even under comparable conditions.

The Mechanical Behaviour of Plastics Materials

Polymeric materials have been found to depart markedly from the classical theories of elasticity and hydrodynamics in their solid and fluid states respectively, and the theory of visco-elasticity has been initiated and developed to describe their behaviour to enable applicational predictions to be made. Elasticity theory was developed on the assumptions of (a) proportionality between stress and strain and (b) absence of any time effect. Plastics materials as solids show departure from the classical theory on both counts; except at low stresses, strain increases more quickly than does the applied stress, and elastic moduli and strength factors (e.g., tensile or flexural strength) decrease with time under load.

Generally speaking, the molecular pattern of plastics materials consists of long chain-like molecules in either random or partly orientated arrangement, and it is this basic structural type which is responsible for the "in-between" or anomalous behaviour of such materials. The long chains can be deformed reversibly, so that the material will behave as an elastic solid; also, the chains can have relative motions, which are irreversible and which on the macroscopic scale impart fluid-like properties. The effect of temperature is very marked in influencing the preponderance of the elastic or the viscous mode. However, both deformation modes are always possible, at least to some extent, at any temperature, so that, when a plastics material is employed to bear a load, thereby making use of its elasticity, time effects obtrude.

An understanding of such behaviour is basic to serious engineering applications of plastics materials and it will be well worthwhile considering certain aspects in more detail. Particularly, the reversible deformations of the polymer structure need to be described, since several molecular mechanisms can occur, differently affected by temperature and hence apparent in different temperature regions. A thermoplastics material has a characteristic softening temperature and, below this temperature, it is a hard solid in which molecular movement is greatly restricted. The elastic moduli are high and deformation under stress is the result of bending at the atomic bonds of the chain structure or of point-to-point displacement of the structure without lateral motion. These deformation processes are largely independent of temperature, so that there is a region in which the physical properties are essentially unaffected by temperature. However, some slight relative motion between chains is possible even at low temperatures over long periods, so that the modulus will slowly decrease as the stress is maintained. As the temperature is increased, relative motion between chains becomes more possible, so that the long interwoven chains can be drawn out. This is the mode of deformation responsible for the large elastic deformation of natural and synthetic rubbers because, as the stress is removed, the chains recover to a coiled form. At still higher temperatures, wholesale relative movement becomes possible, and fluid-like behaviour with irreversible deformation is characteristic. This last condition is made use of in extrusion, injection moulding, and other processes.

The stress-strain response of amorphous and crystalline materials tends to be rather different, but time-effects and temperature-sensitivity are present with each. A so-called crystalline material consists of crystals immersed in amorphous material and, as the amount of crystalline material increases (from one polymer to another or within one polymer type), rigidity increases and the properties tend towards those of a polycrystalline metal, when the size of the crystals and boundary conditions become very significant in their effect on strength and deformation resistance.

Fume exhaust systems and manifold made by Rediweld Ltd. from "Alkathene" polyethylene.
(Courtesy of Imperial Chemical Industries Ltd.)

Many of the well-known rigid or semi-rigid thermoplastics are crystalline to a greater or less extent, e.g. low-density polyethylenes, high-density polyethylenes, polypropylene, polyamides, and formaldehyde. In these materials, the degree of crystallinity varies according to temperature, annealing/quenching conditions, orientation, and other factors. Orientation of the molecules by a stretching process will facilitate the degree of alignment necessary for crystallization to occur and hence tends to increase its extent. Furthermore, the orientation of crystal regions and of the remaining amorphous regions will have a marked effect upon the mechanical behaviour of the plastics material. This effect is now taken advantage of in a number of commercial processes, such as those described below:—

(a) Films are biaxially stretched to increase toughness, a particular example being polystyrene film, which would be excessively brittle without such treatment. The lay-flat process for manufacturing films of polyolefinic materials such as polyethylene and polypropylene imparts a biaxial stretch to the material. Cast films such as polyethylene terephthalate or polyamides are improved by subsequent stretching in two directions.

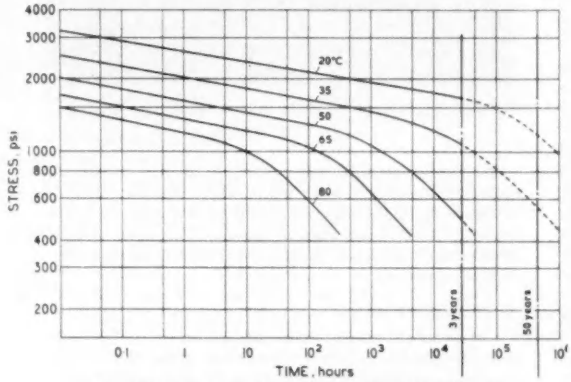
(b) Heavier sheet, made from polymethyl methacrylate is improved in its strength and certain ageing characteristics by biaxial stretching.

(c) Polyethylene tubing also benefits from biaxial orientation. In this case, stretching occurs by reason of an internal pressure and a drawing tension, the material being maintained at the best temperature for such a process, bearing in mind the material properties and the subsequent use of the tubing. Further reference to the effect that stretching has on the properties will be made below when the long-term behaviour of plastics pipe is considered.

Test Data and Engineering Applications

With the increasing use of the rigid plastics many applications have arisen in which load-bearing is significant. These uses have emphasized the need for information concerning the ability of materials to continue to give satisfactory performance for lengthy periods under

conditions of stress. Water-piping is a typical example, others being hinges, castors, and bearings. As already indicated, the all-important fact involved in the engineering applications of plastics materials, whether rigid, semi-rigid, or elastomeric, is that the strength properties are time-dependent. Consequently, specification tests, which tend to define certain testing rates sufficiently high for the test to be completed in a relatively short time, do not yield information of direct use in predicting long-term behaviour. There is a need, which is becoming increasingly more urgent, to relate short-term tests to long-term performance and to build up a background of information and data concerning behaviour over periods of from 1 to 25 years, depending on the application.



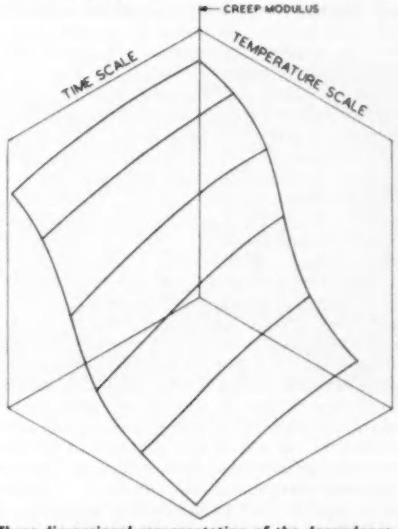
Hoop stress as a function of time to burst, at different temperatures, for high-density polyethylene pipe.

One of the most significant applications in focusing attention on the need to collect performance data has been the use of plastics pipe, especially P.V.C. and polyethylene pipe for cold-water services. Long-term tests have been set up in which pipe behaviour has been studied for a range of internal pressures (water and air) and at different temperature levels. Of particular interest are the life of the pipe before bursting occurs and its correlation with short-term bursting tests. Since processing and material factors have an effect on the behaviour, testing programmes are extensive undertakings when they must run for up to 25 years to give the complete story. Since material and formulation changes are always being introduced, the materials manufacturer has a serious and expensive problem in obtaining adequate data.

For pipes, it is usual to plot the hoop stress against time to break at different temperature levels. Hoop stress can be calculated in terms of $PD/2w$, where P is the internal pressure, D is the mean diameter, and w is the wall thickness. Except for the fact that this formula does not accurately represent the maximum hoop stress for a small-bore or thick-walled pipe, it is a reasonable means of correlating the results for different bores and wall thicknesses. Pipes will withstand moderate internal pressures for a long period and then develop fine longitudinal splits without apparent deformation—a brittle break. High internal pressures will cause rapid rupture but considerable deformation will then occur—a ductile break.

Some success has been achieved in relating the behaviour at different temperatures and in extrapolating to longer times. Tests on pipes from high-density polyethylene have been running continuously now for about 5½ years,* and these have served to show that the life curve, obtained by plotting the logarithm of hoop stress as a function of the logarithm of the time to burst, consists of two linear portions connected by a knee, the first part corresponding to high stresses and ductile failure, and the second to the region of brittle failure, as shown above. From the collection of such data, specifications have been drawn up and reasonable safety factors have been chosen.

Gloor† has demonstrated that the patented process of biaxial stretching of polyethylene pipe increases its creep rupture strength about twofold, permitting thinner gauges to be employed.



Three-dimensional representation of the dependence of creep modulus on time and temperature.

Advances have been made in using plastics for pipe engineering not only because of the demand, but also because of the relative simplicity of the stress-strain relationship, since all pipes have the same geometry, and, to a sufficient degree of accuracy, the same hoop-stress formula applies. Other applications may have more complex geometries and be more individual in respect of stress-strain relationships. Applicational problems can be solved with adequate accuracy by using basic plastics data, obtained from creep or stress-relaxation tests, allied to formulae for stresses and deflections given by classical theory. The appropriate classical formula is chosen, and the modulus or strength values obtained from the tests, appropriate to the expected life of the stressed piece, are inserted to enable dimensions to be derived.

The larger manufacturers of materials are gradually collecting and publishing data suitable for use in this way. Research engineers are seeking to relate stress relaxation and creep, and to understand long-term breaking phenomena so that prediction from laboratory tests can safely be made up to very lengthy periods. Gradually, old-style property charts will be replaced by the information mentioned above. In its complete form the data will

* K. Richard and R. Ewald: *Plastics*, Vol. 24, 1959, p. 153.

† W. E. Gloor: *Modern Plastics*, Vol. 36, No. 2, 1958, p. 144; and Vol. 38, No. 3, 1960, p. 111.

consist of a three-dimensional model, using a vertical axis for the creep modulus for small deformations, and the two horizontal axes for temperature and time, as shown above.

Applications of Plastics in the Engineering Industries

A recent review of plastics suggested that it is possible "to measure the progress in plastics in terms of the engineers it has conquered". Enigmatical as this may sound, it is certainly true insofar as British industry is concerned, for, until recently, there can have been no more difficult task for any salesman than to convince the average engineer in a traditional British industry that plastics could provide the answer to his problems. It is one of the encouraging signs of the development in British plastics in the past year or so that one after another of the traditional industries—general engineering, mining, the foundry, agriculture, and shipbuilding—have accepted plastics as constructional materials suitable for serious consideration and trial. On the other hand, it must be admitted that, from the earliest days of plastics development, some industries (such as the electrical industry) found traditional materials unsatisfactory for their growing needs and were not only willing to give plastics a fair chance, but also, in many cases, to give active aid in the development of new plastics materials and manufacturing processes.

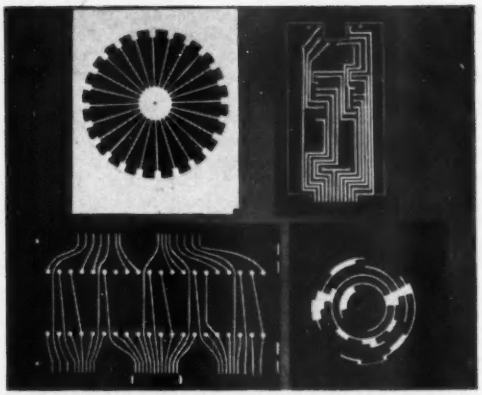
This should not be taken to mean that the way is now clear; far from it, particularly in Britain. There are still many engineers, especially on the heavy structural side, who have yet to be convinced that plastics can play a role comparable with that of metals and ceramics. This attitude is quite reasonable, as these men cannot afford to take risks with the use of new materials in the absence of conclusive performance data. However, the corner has obviously been turned and, with new and improved materials applied to better design, even the most sceptical should eventually be convinced.

So wide is the current application of plastics, and so diverse the fields of industry into which they penetrate, that it is possible in the following to give but the briefest survey of current progress.

Electrical and Electronics Industries

As has already been mentioned, plastics are especially suitable for the electrical industry, including electronics and telecommunications. It must not be forgotten that it was the availability of polyethylene in the early years of World War II which made radar possible. The provision of innumerable mouldings or of vacuum-formed sheets or polyester laminates for electrical apparatus is now commonplace, but so rapid and numerous are the developments which are announced almost simultaneously that we are apt to overlook the fact that plastics played a significant part in making possible such developments as printed circuits, potted circuits, and components, and the numerous minute transmitters and microminiature apparatus which has cut to a mere fraction of their bulk such items as radios, television sets, and personal hearing aids.

On the heavy side of the industry, and particularly in submarine cables, plastics are playing an increasing part, making possible increased efficiency at a reduced overall cost. For power transmission, from the smallest highly coloured domestic wire to the heavy-duty cables from generating stations, plastics now predominate. On the



Some of the printed circuits produced in Bakelite copper-clad laminate materials, as used in the Ferranti "Mercury" computer.

(Courtesy of Bakelite Limited)

electrical-fitting side, plastics have revolutionized the industry in less than a decade. Thus, from the extruded conduits and moulded switches and junction boxes to the extruded transparent shades for striplights, plastics meet increasingly stringent needs functionally, aesthetically, and economically.

Transport Industries

It is not surprising that plastics found favour with aircraft designers after the experiences of the last war. It was perhaps disappointing that, in the earlier days, motor-car manufacturers and the shipbuilding industry did not respond as enthusiastically as could have been expected. As far as motor-cars were concerned the deterrent was in the main an economic one; with the shipbuilders it was tradition. That there has been a change in heart in both is very encouraging for plastics.

Some time ago, the chief research engineer of a large British car-manufacturing combine suggested that it should be possible to use up to 5 cwt of plastics in each car produced. This would, of course, include the tyres and body, and (most surprisingly of all) the cylinder block. If this optimum could be attained it would mean that, with a conservative production of around one million cars per annum, the British motor-car industry might be expected to use up to 250,000 tons of plastics per annum, which is just short of half our current total production. From the progress made in the last year or so, it is quite clear that, even if this optimistic view is not attained, the use of plastics, at least as fittings in cars and for special body-work, will increase.

That plastics were readily accepted in the aircraft industry was to be anticipated and, whilst special metals will no doubt persist for airframe and fuselage construction, their use will extend in fittings and internal work generally. They will, of course, come in question when special temperature requirements have to be met, as in the case of space vehicles and rockets, some of which, particularly in Russia, have been reported to use organo-metallic polymers in one form or another. Reinforced-plastic nose-cones for rockets are to-day a commonplace, and critical points in jet aircraft, such as the tail-plane in the Boeing 707, rely on plastics to some extent to give the critical performance required.

It is possibly in the field of marine engineering that plastics have made their most recent and most significant

triumph. Until a few years ago plastics had little hope of significant use in anything other than small domestic and high-speed service craft. The changed attitude actively stemmed from the symposium organized in 1958 by the Institute of Naval Architects, to bring together those responsible for the building of liners and those manufacturing and applying plastics. Since then, a number of the large shipbuilding lines have revised their attitude towards plastics. A notable example is the "Canberra", launched by the P. & O. line last year and due for her maiden voyage this spring. When the liner is in service she will have nearly £500,000 worth of plastics goods and materials within and on her hull. Polyester glass-fibre mouldings are widely used, the largest of these being a combined shower and W.C. compartment. The wash-basin in all the first-class cabins is enclosed in a glass-fibre moulding incorporating a toilet cabinet with a mirror-faced door, with a recess for toilet articles immediately above the wash-basin. These two units are so designed that they can normally fit together in the cabin to give complete toilet facilities.

Tools and Equipment

Plastics find extensive application in the manufacture of what may be termed tool ancillaries, i.e., handles, guards, and housings, which are essential to the tools and which have hitherto been a metal monopoly. Shock-resistant plastics handles for tools have long been available and have added to their efficiency and ease of handling. Plastics are, of course, of special interest in the production of electrical tools, where the predominant use of metal has always presented serious insulation difficulties.

Plastics have made their mark as primary materials in the construction of moulds and pressing tools for metal formation. This development dates back to the last war, when ethyl cellulose composition formers were used in the pressing of metal aircraft-wing sections, but, since then, and particularly since the advent of the epoxy resins, they have been more widely applied in this field. The use of plastics pressing tools gives greater precision, lower power consumption, and increased die and mould life. The actual time required in casting the plastics moulds, as also the ability to vary them from time to time, are attractive features which have offset some of the preference which engineers formerly had for the traditional metal prototypes.

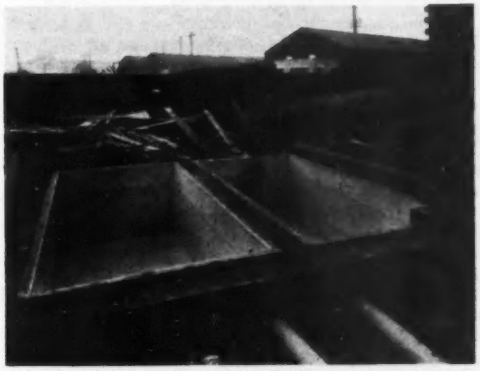
Plastics, of course, play an ever-important part in providing general equipment for the engineering industries. Housings, guards, and shields have been already referred to. Conveyor belts are now mainly plastics-coated, and in many cases the belt itself is constructed in nylon or Terylene fibre.

The foundry, one of engineering's most traditional divisions, which resisted the use of plastics for many years, finally succumbed to the overwhelming superiority of plastics in the production of moulds. In this connection, plastics have made possible the shell-moulding technique perfected by Cronin during the war.

The possible extension of plastics in fields associated with heavy engineering equipment, such as cranes, light bridges, water and cooling towers, etc., is foreshadowed in pioneer work now being directed both in this country and in Germany towards the use of plastics adhesives in place of conventional metal bolts in the production of these structures. It is well known that much of the stress is centred in the bolt and that, if the load can be spread along the whole of the mating face, freedom from the development of brittle fracture will be assured, and the life of the joint correspondingly increased. It may be that, in the not too distant future, a few bolts only will be used in a structure, and their function will be to hold it together during erection and not during its useful life.

Chemical Plant

Strangely enough, in the past the chemical industry has not given the lead which might have been expected in the active use of plastics in its producing units. More recently, however, the larger companies producing raw plastics have made a particular sales point that plastics of one type or another are being used in plant and laboratory construction, and this is particularly the case where difficult working conditions are encountered.



"Alkathene"-lined tanks, made by Prodorite Ltd., at the I.C.I. Ltd., Metals Division Amal Works, Witton.
(Courtesy of Imperial Chemical Industries Ltd.)

In the main, the use of plastics in the chemical industry is confined to the lower-temperature applications. Pipes, ducting, and guttering possibly form the bulk of the demand, but equally important from a critical functional point of view is the use of flexible plastics as valve seatings and glands. Reinforced plastics are also being increasingly applied in the production of containers, storage vessels and in some cases reaction vessels, plating baths, etc. However, the flammability of these materials has in the past been a serious disadvantage, and one indeed which has made many manufacturers cling to the traditional metals. In this connection, it is of interest to note that British Resin Products have developed a flame-retardant polyester/glass sheeting, which is made from "Cellobond" polyester resins, specially formulated for very low flammability. Local authorities can now permit the use of this sheeting, which is light in weight, very tough, and can be nailed into position.

It is interesting to note that, although resin-bonded fibre-glass static vessels have been successfully used in the chemical and allied industries, they are encountering growing competition from vessels made of thick polyethylene, slush-moulded or formed from comminuted polyethylene by thermofusion processes. This development makes it possible to produce very large industrial units without the usual very heavy mould costs.

Finally, in considering the part plastics play in chemical plant, we must not forget the growing interest in the combined use of plastics and metals. This admittedly is a new twist to an old idea, but in its modern form the dip-coating of metal with plastics melts or packs, or coating with plastics applied by the fluidized-

bed technique and subsequently fused, completely outclasses the pioneer and somewhat tedious and costly application of protective lacquers for many purposes.

Methods of Processing

In this section a brief description is given of the more important processes applied to plastics materials, with attention concentrated on trends in techniques which have an effect on product quality and design capabilities. Traditional methods of sawing, machining, welding, cementing, etc., are not considered, though they are entirely applicable to plastics materials, given reasonable skill.

Compression and Transfer Moulding

These long-established processes are still important features of the moulding industry and are not without their modern developments. They have continued to be important because thermosetting materials are still of value in both the industrial and domestic fields. Thermosetting materials have, as their name clearly suggests, certain advantages in respect of temperature resistance and general inertness. As practised with phenolic, urea, and melamine resins, compression moulding tends to be slow by modern production standards, but considerable improvements in curing time can be made by preheating, these improvements being especially marked when heavy-section mouldings are required. The introduction of alkyd resins has made possible markedly shorter curing times and has necessitated the development of fast-acting presses.

Developed from conventional compression moulding, the transfer-moulding process has extended the facility and range of thermoset moulding, especially when preforms are used and radio-frequency preheaters, closely integrated with the press cycle, are employed. Since best advantage can then be taken of the easy flow characteristics which exist for a short time in the heating-curing process of a thermosetting resin, thinner sections, more slender inserts, and better distribution of flow can all be achieved. This is especially true in the case of epoxy and polyester compounds.

To gain the properties of strength and toughness required for many applications, or to modify high-temperature characteristics, reinforcing fillers are employed in the formulation, the flow behaviour of the material then being considerably modified. Attention must be given in product and mould design to the flow pattern, filler alignment, and the possibility of separation between resin and filler. Surface finish is closely related to the nature and content of filler.

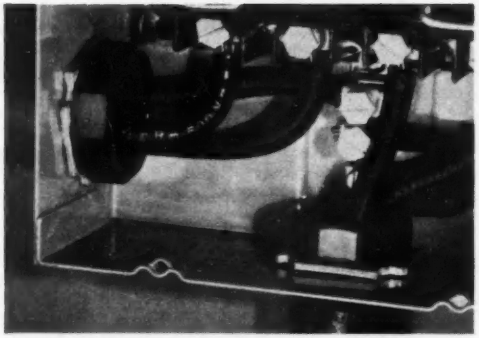
Injection Moulding

Probably more injection machines are in operation than any other processing technique, yet something of a revolution is taking place in machine design. In the past, use was made of a heating cylinder in which heat transfer and pressure transfer were conflicting design requirements; now, however, increasing attention is being given to preplasticizer designs in which these basic functions have been separated. Many styles of preplasticizers have been tried, but the single-screw type is making most headway. At least three British manufacturers of injection machines now use such a device as the heart of their machines. By rotary motion the screw acts as a preplasticizer as the material is warmed, softened, and fed forwards, and, by axial motion, as an injection plunger to transfer material into the mould. By thus separating these two functions a considerable increase in machine efficiency has been achieved and, more important, an improvement in product quality gained.

Since the process, to be economical, employs relatively cold moulds, the heat-softened material must flow in over chilling surfaces. Chilling restricts the flow of material against the walls, and further flow must occur through a reduced channel, causing dragging against the inside surface of the chilled layer. As a result, there is a severe orientation of the polymer molecules in planes parallel to the mould wall, depending on the intensity of cooling, the rate of flow, and the gap thickness. The ultimate effect of chilling against the wall is to limit the length of flow, so that reduction of wall thickness greatly restricts the length of flow. The moulding of thin sections becomes very difficult, but the situation is improved by faster filling, made possible by increased pump capacities and increased pressures. Chilling also results in severe stresses being set up which can cause warping in the finished moulding and, in certain materials, will lead to stress cracking. Chilling and orientational effects are never absent from injection mouldings and are usually more of a hazard for this process than for any other. In certain cases, it becomes necessary to carry out annealing procedures to obviate the effects of the chilling stresses, though orientational effects, which cause the strength value to be different in different directions, are not eliminated by this treatment.

Since the injection process is usually carried out at a temperature well above the softening point of the material and since plastics materials as a class have high thermal expansion coefficients, the dimensions of the cooled moulding differ considerably from those of the mould. This moulding shrinkage is frequently a source of difficulty in engineering applications where close tolerances are required in tha t it is not an easy matter to make allowances in dimensioning the mould. Consecutive mouldings are fairly close to one another in dimensions, provided that machine conditions are maintained steady, and the difficulty more often than not lies in designing or adjusting the mould correctly at the beginning. Materials vary markedly in their shrinkage values, with crystalline materials shrinking two to three times as much as an amorphous polymer. The direction of flow in a mould is also significant, heavier shrinkage occurring more along the flow than across it. This effect is very marked with crystalline materials. The preplasticizer types of machines are superior in reducing the stress level in moulding by preparing a more uniform shot of material and in being more consistent from shot to shot, enabling a greater dimensional accuracy of moulding to be obtained.

If more than a few tenths of a percent of moisture is absorbed by the material, drying will be necessary, or at least advisable. Immediately after moulding the material will not be in equilibrium under normal ambient conditions and moisture will gradually be regained. This can result in significant dimensional changes with some materials, e.g., polyamides and cellulosic compounds. The wall thickness of a moulding is significant in a number of other ways. Changes of thickness are particularly serious in that they cause awkward stress patterns to develop during moulding, as well as stress concentration in use, and can affect the economics of the process by lengthening the curing time. If a moulding can be considered as a slab of material of a given thickness, the cooling time, for the same material and mould



"Tenite" cellulose acetate butyrate insulating bushings, made by The Thomas & Betts Co., Inc.
(Courtesy of Eastman Chemical Products, Inc.)

temperatures, will be proportional to the square of the thickness. For economic moulding the thickness must be kept to a minimum, whereas, for stiffness and toughness, it must not be reduced. Careful design is therefore necessary to effect the optimum compromise. Cooling times in injection moulding are so important in controlling the total cost of the process that the ideas of one British manufacturer of machinery are extremely interesting: A turret of moulds is employed so that cooling can proceed for one moulding while succeeding shots are being made.

Extrusion

It is probably true to say that no type of equipment is of more value to the plastics processing industry than the extrusion machine. It is used in its own right to produce pipes, sections, sheet, and film to cover wire and to coat and laminate.

Single-, double-, or even triple-screw machines are employed, though by far the greater number in service have a single screw. The products of the extruder become the raw material of later users, who are thus in the position of having to understand the inherent characteristics of extruded products. Since so many different types of product are made with a wide range of thermoplastics, it is not possible to give any detailed comments; certain general points are, however, of significance. The extrusion machine is employed to plasticize, to homogenize, and to force material through some form of die and, generally speaking, these operations are performed with efficiency if the extruder is well designed and correctly controlled. Product quality, however, can be inadequate if design and operation are poor, resulting in non-uniformity and excessive strain within the extrudate. Even under the most ideal conditions some orientation and directional effects in regard to properties will be present, necessitating due allowance in critical subsequent processes or applications. Section extrusion presents some die-design problems. Thus, the rate of flow through a die section is affected strongly by its dimensions so that, without due care and adjustment, some parts of the section will flow faster than others.

Extrusion Blowing

This is the method whereby plastics hollow-ware such as bottles can be made. Basically an extrusion machine with a vertical tube die is employed to make a length of tube, called a parison, which is nipped off by a mould and blown by air pressure. A wide variety of thermoplastics can be blown in this way, provided that the melt viscosity is sufficiently high to permit a suitable parison to be made. Increasing industrial interest in this process can be expected, and it has already had a tremendous impact on packaging. Article design is largely a question of making the correct parison and minimizing the effects of top and bottom welds.

If the final shape is more or less cylindrical, the material is stretched uniaxially and this can affect the properties, especially impact resistance if this is marginal. If the shape departs from that of a cylinder, the wall thickness of the article will vary. Some variation in thickness is also caused by draw-down in the parison. The material is in the rubbery region during blowing and will retract if heated or softened by attack from solvents. Since the process lends itself so readily to container manufacture of all kinds, assessment of resistance to the contents is important.

Extrusion Casting

Small extrusion machines can be used as material pumps to make large articles from materials such as polyamides (e.g., Nylon 6). Usually a higher-viscosity resin is used, and the only serious limitation is the size to which moulds can be made readily; thickness is no limitation. Since the moulds do not have to withstand high pressures, simple constructions of fairly low cost are feasible, so that short runs are economical. The mould is clamped to the outlet of the extruder and is cooled progressively as it fills, the pumping action of the extruder being maintained as cooling proceeds to make up for shrinkage. This method was originally developed for use with polyethylene for the manufacture of heavy-section rods and large mouldings.

Truck wheels, boat propellers, couplings, heavy gears, and other solid sections, around inserts or shafts if necessary, are recent examples of the use of polyamides, while stock sheets or rods, from which prototypes can be machined, are standard lines.

Thermoforming of Sheet

Under this heading is grouped a series of closely related techniques, unique to the plastics industry, in which materials in the form of sheets are softened and shaped by the application of differential pressures, which may be supplied by mechanical movement, by air or some other fluid, or by vacuum. By modification of the procedure (known as plug-assist or air-cushioning), deep drawing and good control of wall thickness can be achieved, giving an impressive range of products from small containers to large housings. For small items of thin wall-section and for large formings, the method is in competition with injection moulding, and product designers must consider the potentialities of both processes and assess them on merit against requirements.

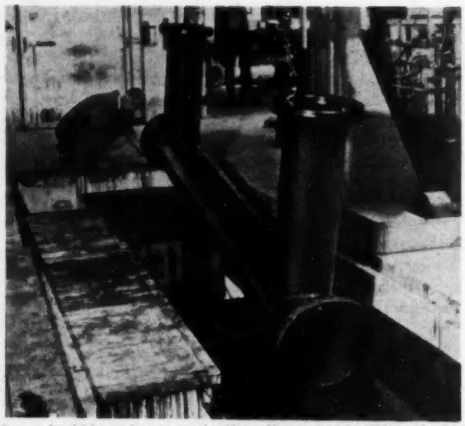
For thermoforming the sheet materials are heated to temperatures above the softening point into the region where they function largely as elastomers. As the material is formed the molecules are drawn out to a new pattern, into which they set on cooling. In use, a rise in temperature to around softening point will result in a tendency to un-form; stability in this temperature region will depend on the extent of strain.

The ability of materials to deep-draw is limited and for any one material depends on the temperature and speed of draw, with marked variations from one material to another. In article design, sharp changes in profile

should be avoided, since these will cause excessive thinning and strain, in spite of improved techniques.

Powder Coating

Methods whereby sound thick coatings of decorative or protective plastic coatings can be placed onto metals have considerable industrial importance. This can be done with flexible P.V.C. from paste baths, but greater versatility in respect of materials is given by the powder-coating process, by means of which P.V.C., polyolefines, cellulose acetate butyrate, epoxy resins, and nylon can be applied. In this process, fluidized beds of fine powder form a bath into which the heated articles are dipped, the powder clinging as it is softened by heat from the article and forming a continuous adherent coating either immediately or on further heating in an oven. Article temperatures must be selected to suit the thickness of metal and the nature of the powder, and the final sintering temperature must be carefully controlled to avoid damage and heat degradation. Sharp edges must be avoided, if possible.



Part of a 14-in. salt-water pipeline, dip-coated in "Vylastic RS" polyvinyl chloride.
(Courtesy of British Geon Ltd.)

An important variant of this general principle of deposition involves sintering and is employed to make some of the largest thermoplastic articles. A hot hollow mould is filled with, say, polythene powder, which is then poured out again, leaving behind a fused residue on the mould walls. After sintering and perhaps a second filling-sintering stage, a continuous reproduction of the inside mould surface can be removed. Large bins and light boat hulls are among large articles made in this way.

Conclusion

It is possible that, apart from the considerable process and chemical advances which have been made in the plastics industry since the war, the most significant step forward ever made has been the realization that plastics can be used as materials of construction in their own right, and that they can co-function with traditional materials to yield end-products superior to those obtained from new or old materials separately. Equally significant has been the realization that design in plastics must take note not only of the properties of the end-product, but also of those of the plastics materials or materials used in relation to the processes operated to manipulate them. In other words, as has already been stressed, it is essential to design *in* as well as *for* plastics. Thus, where it is decided to change over from metals to plastics, it is essential to take into account not only the relative strength of common sections, but also to remember the fact that, whereas the metal unit can frequently be fabricated from standard metal sheet or rod, the plastics counterpart usually has to be moulded from powder, and that strength can therefore be affected quite considerably by the flow pattern in the mould and by any stresses which might in consequence be "locked" in the moulded unit.

It should be noted that many early moulded plastics units have failed dismally simply because the manufacturer slavishly followed the lines and dimensions of early metal or ceramic prototypes. To attain this realization has, inevitably taken some time and not a little courage, since in many cases it has meant a considerable, if not complete, break-away from long-cherished tradition. Once this lesson was learnt, the overall result was beneficial, not only for plastics, but for product design in general. Once designers were freed from the inhibitions engendered by generations of metal prototypes, they gave their imagination full rein and capitalized to the full all the properties of plastics, including their remarkable colour potentialities. No longer is it necessary, for example, to disguise the inevitable mottle in a moulded phenolic cabinet as "synthetic" oak or mahogany; to-day a plastic is a plastic and does not need to pass under the guise of any other material. This appreciation has resulted in the development and extensive application of new materials and new functional forms. In few products has this been so apparent as in such attractive laminates as "Formica" and "Warerite", which form an indispensable part of almost every modern home. It was colour, among other properties, which attracted the manufacturers of toys to the use of plastics, and it was likewise the possibility of combining colour, both transparent and opaque, with attractive shapes, which made plastics the ideal material for the production of non-brittle containers for foodstuffs, medical preparations, and cosmetics. Here again, the change-over from glass or tin plate to plastics made possible a radical break-away from designs which had been traditional for generations.

In the industrial field, the introduction of plastics has also made possible radical changes in design of large and frequently heavy-duty units. Plastics bearings for rolling mills have simplified design by reducing lubricating problems, and, in the same engineering category, the use of the relatively expensive P.T.F.E. as gland packings has rapidly become successful, despite the fact that the new materials originally cost over £20 per pound. Similarly, nylon gears have simplified the design and cut the overall weight and power cost of intricate gearboxes for special applications, whilst glass-fibre-reinforced polyesters have been used in washing machines for attractively streamlined machine housings and bodies, which are both economic in production and functional in application. These are a few examples taken at random, but they should be sufficient to show the progress made in design as a result of the application of plastics.

In the early days of the plastics industry in this country, there was considerable criticism of the design of pioneer plastics units, as much from the aesthetic as from the functional viewpoint. Although, in the main, Britain at first lagged behind America in the appreciation of the significance of good design in plastics application, any such deficiency has long since been made good, and to-day British plastics design is second to none.

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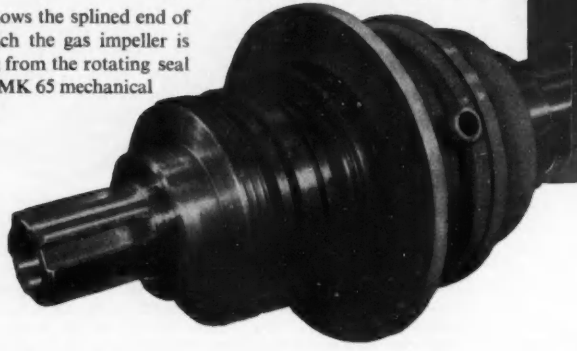
Top Left: Two of the steam raising units are shown here already in position against the background of the general construction work in progress.

Right: The complete impeller shaft assembly is shown alongside the domed end impeller casing in which it will be installed.

Below right: This shows the splined end of the shaft upon which the gas impeller is mounted, projecting from the rotating seal face of the CRANE MK 65 mechanical shaft seal unit.



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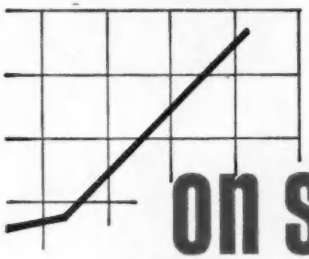

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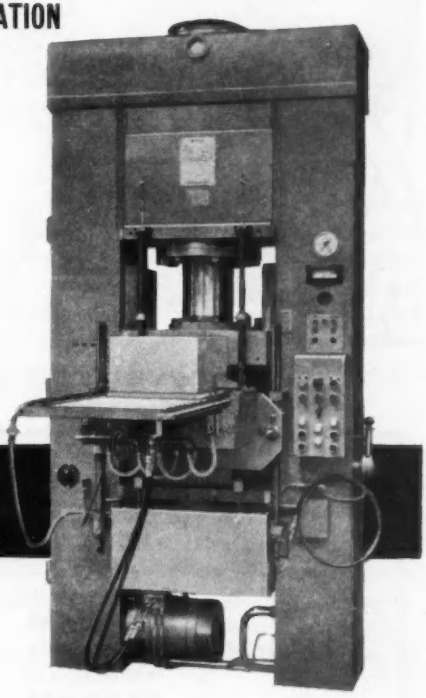

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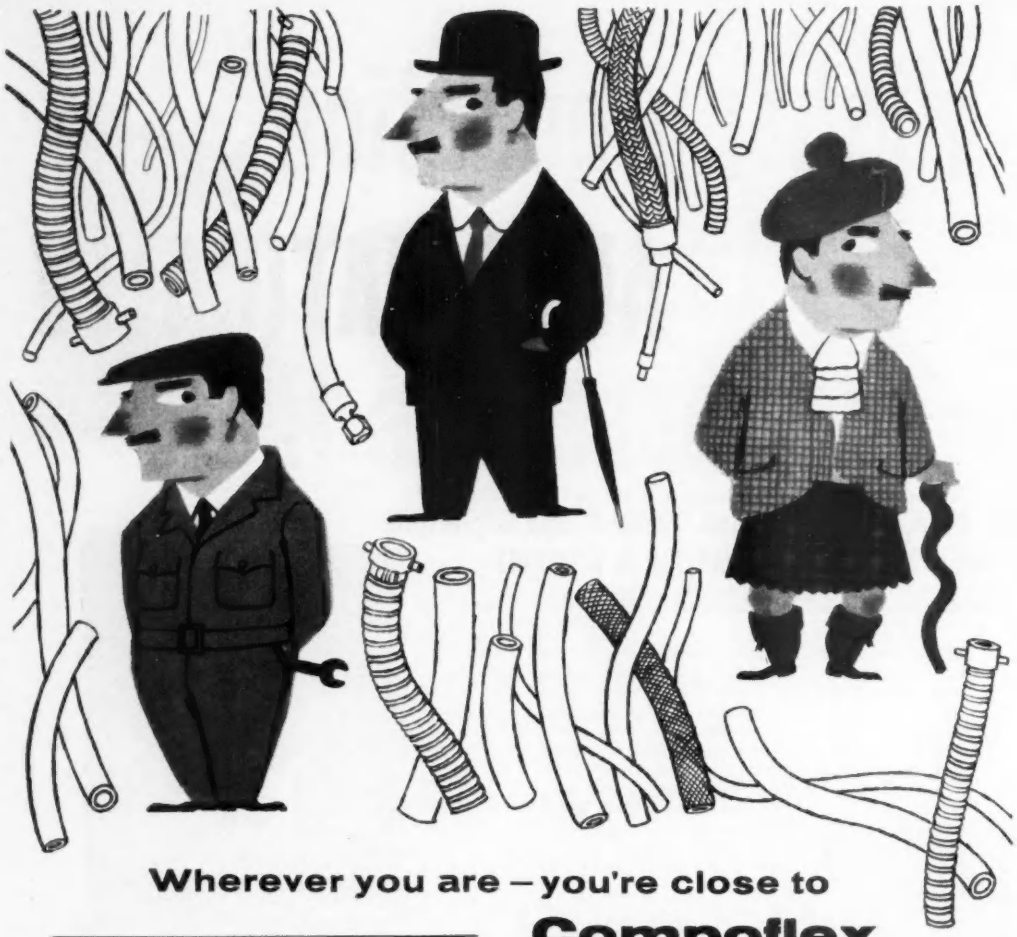

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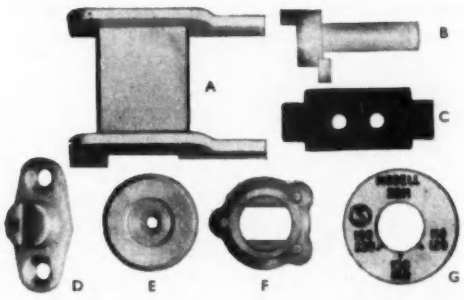

A. Coil Bobbin. Nylon A100M
B. Bearing Arm. Nylon A100M
C. Terminal Plate. Bakelite X20/5 HD
D. Voltage Selector Knob. Nylon A100M
E. Starter Wheel. 'Welvic' P.V.C. Medium Hard
F. Retaining Plate. Nylon A100M
G. Voltage Identification Plate. Melamine M4910
The body is moulded from Melamine M4910 and the Head Guard not shown) from Styrene Acrynitrile

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For more information on physical properties and uses, contact

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high dimensional accuracy
high compressive strength
high impact strength
good resistance to abrasion and corrosion
absence of cold flow
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. . . all in all, an impressive list of properties. No wonder, then, that so many rubber manufacturers are producing mechanical mouldings in Silastomer. Get their names and addresses from *any* Midland Silicones branch office.

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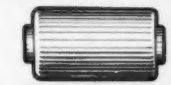

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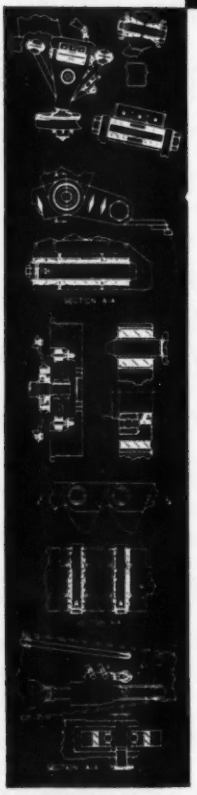

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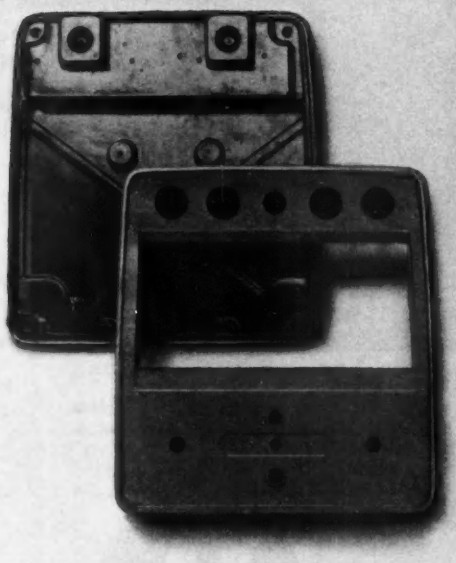

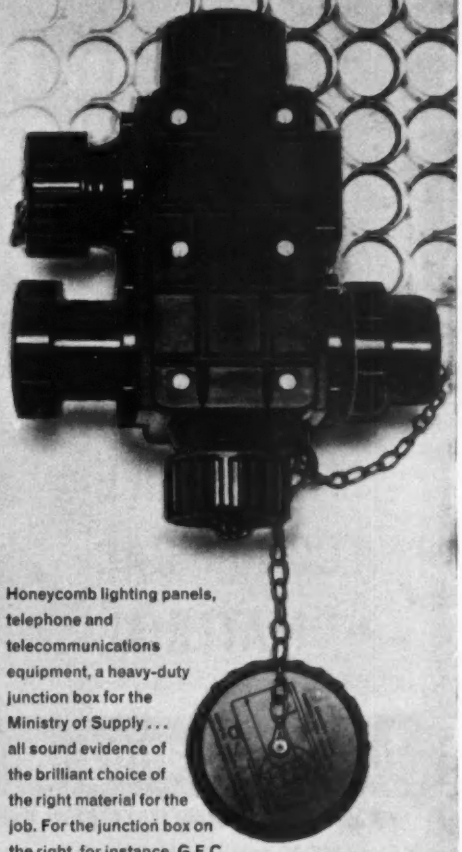

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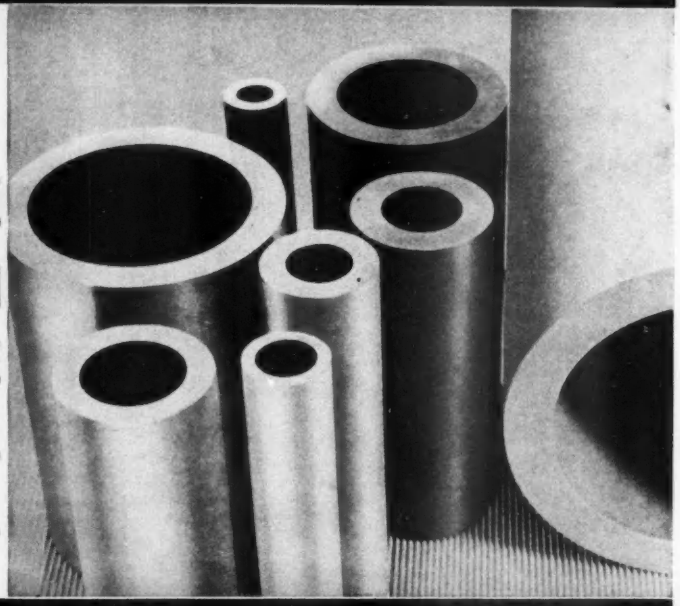

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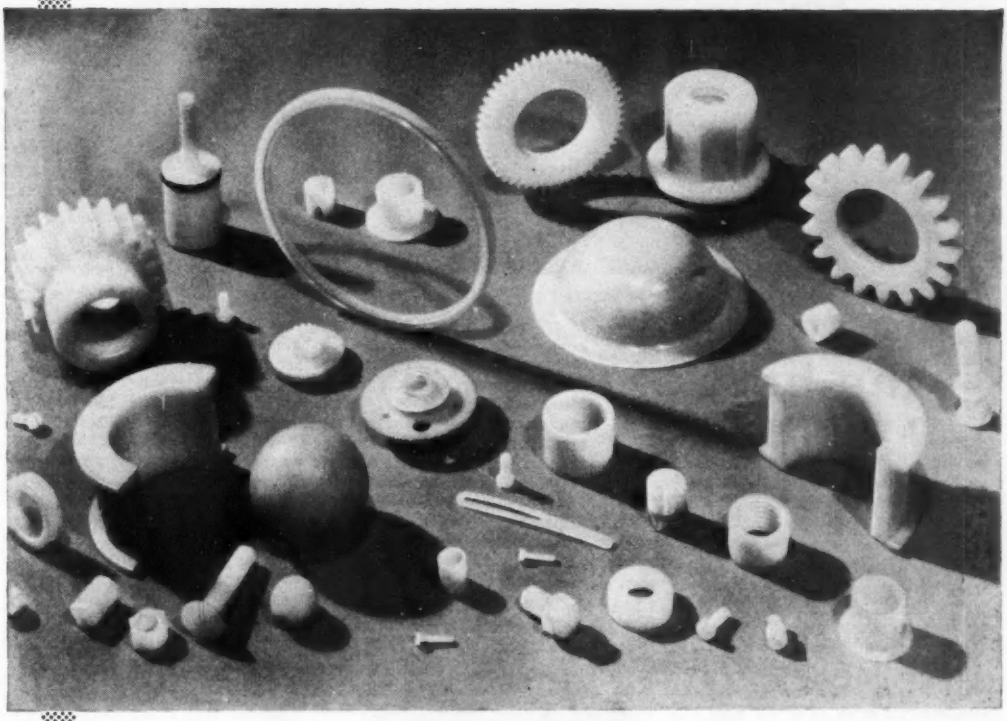

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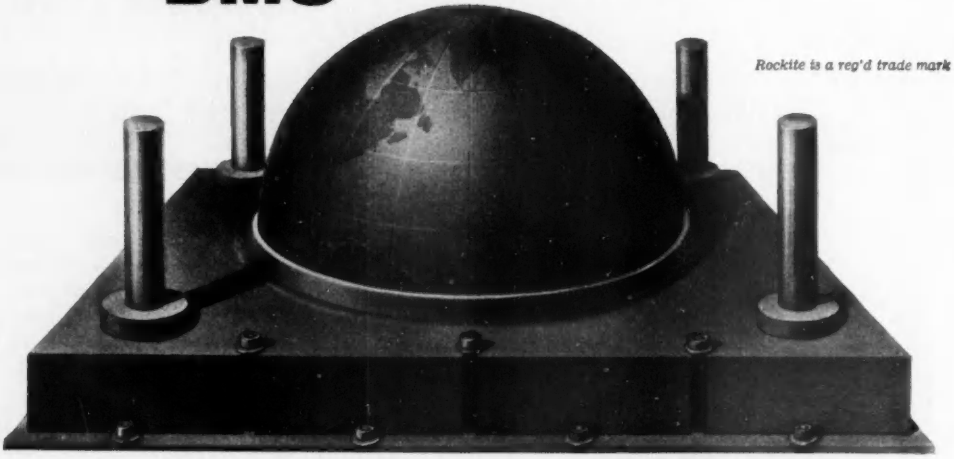

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Distillers Plastics Serve Everyman

British Industrial Developments

Submerged Chemical Pumps made from Titanium

About a year ago, the Nobel Division of Imperial Chemical Industries Ltd. became interested in the possibility of using I.C.I. titanium for a pump handling 99·8% nitric acid, as they considered that a titanium pump would have a longer life and would require less maintenance than a pump using the 18/8/Nb stainless steel previously used in their existing vertically submerged pumps for this purpose.

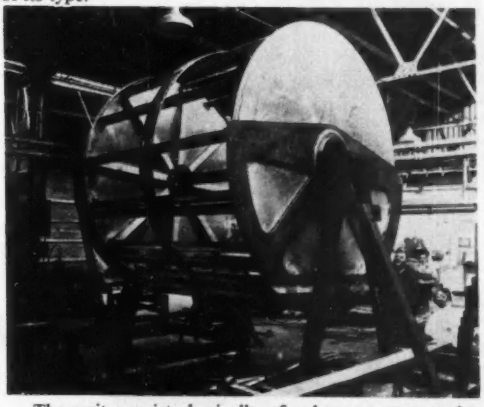
As a result of discussions with Appleton & Howard Ltd., of St. Helen's, Lancs., a suitable submerged pump made from titanium was designed with a view to ensuring little maintenance, reliability in operation, and complete safety when pumping the highly corrosive concentrated nitric acid, since the gland would not be under liquid. As the submerged length of the pump was to be about 8 ft 9 in., centre steady bearings were essential along the support tube, and it was at first thought that these would present some difficulty. However, Appleton & Howard had already developed a successful pure P.T.F.E. bearing for submerged pumps handling hydrofluoric acid for the United Kingdom Atomic Energy Authority, and, with a view to increasing the rigidity of the P.T.F.E., comparative tests were made in 99·8% nitric acid on P.T.F.E. loaded with molybdenum disulphide and with stainless-steel powders. It was found that the bush loaded with molybdenum disulphide swelled considerably, whereas the bush loaded with stainless steel was satisfactory and showed no ill effects. This submerged pump, known as the "Gush", has now been operational for about 7000 hr at 1440 rpm and is reported to be running as smoothly as when it was installed, with no noticeable vibration (usually due to wear on the steady bearings). As a result, three more similar pumps have since gone into operation to replace those previously made in 18/8/Nb stainless steel.

Because of the limitation in the size of the pumps which can be lined, Appleton & Howard have departed slightly from the traditional pump shape and have designed their units to suit welded fabrication techniques. Thus, instead of relying on a cast-iron casing to provide the required strength, they use titanium of slightly heavier gauge and apply stiffening ribs where necessary. As a result, there is almost no limit to the size of pump that can be made at a very economical price. Also, with increased usage and familiarity with titanium welding techniques, site repairs on solid titanium pumps will be readily handled by works-maintenance shops.

A range of horizontal pumping sets is now available in the "Gush" series with heads of from 10 to 150 ft and capacities of from 2 to 1000 gpm. All wetted parts are in solid titanium, and either packed glands or Crane Type-10 mechanical seals can be supplied in all these units. Where abrasive solids are present and a packed gland must be used, the titanium protective sleeve at the gland is coated with a minimum of 1 mm of ceramic. Submerged pumps can now be supplied with P.T.F.E. bearings loaded with ceramic powder, stainless steel, nickel, glass, or carbon, the latest possibility being P.T.F.E. loaded with titanium. In this connection, it will be appreciated that one of the problems with a pure P.T.F.E. sleeve bearing has been its bad cold-flow characteristics, mainly because of the local heating effect of the rotating shaft, especially at comparatively high speeds, e.g., 2885 rpm. The use of loaded P.T.F.E. has to some extent reduced this tendency but, in addition, the Appleton & Howard sleeve bearings used in the "Gush" series of submerged pumps are of unique design, being, in effect, small heat exchangers and ensuring that the temperature of the bearing is even throughout, irrespective of the liquid level in the vessel, and eliminating the cold-flow effect. All these pumps are fitted with P.T.F.E. washers as a seal between the tail end nut and impeller, and between the impeller and shaft sleeve, to prevent the corrosive liquid from attacking the high-tensile shaft core.

Rotary Coolant-Filter Unit

Capable of filtering 830 gpm, a rotary coolant filter of unique design has been developed for use with the new 72-in. cold mill now being installed by James Booth Aluminium Ltd. at their Kitts Green works, Birmingham. The filter unit, which is designed to keep the mill coolant uniformly clean, so that the rolled products produced have an exceptionally high-quality finish, was designed by The Loewy Engineering Co. Ltd. (Bournemouth) in conjunction with James Booth, and was fabricated by Windshields of Worcester Ltd. Measuring 12 ft in height, more than 20 ft in length, and 10 ft in width, and containing 8000 gal of paraffin coolant, the filtration equipment itself, and two coolant-circulation pumps, this unit is believed to be the largest aluminium structure of its type.



The unit consists basically of a large storage tank, with a drum of 10 ft in diameter and 9 ft in length mounted transversely across the inside and free to rotate about a horizontal axis. The outside of the drum is of fine wire mesh, over which are led two continuous, tensioned webs of filter paper, 50 in. in width, with feed and take-up mandrels located above the main tank.

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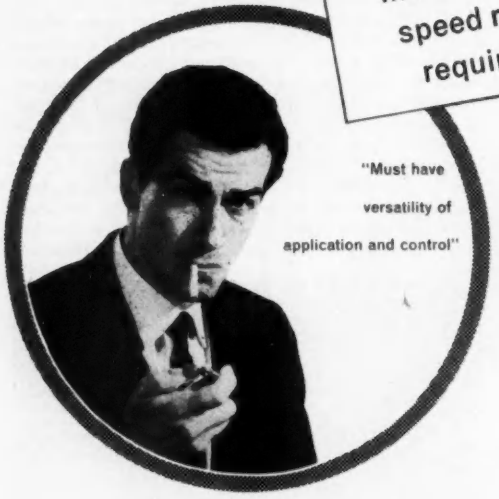
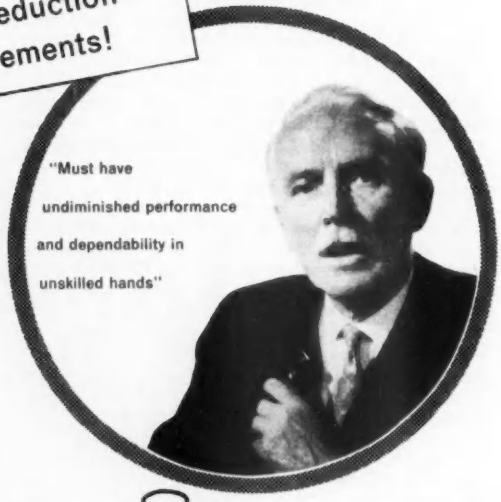


"Must have versatility of application and control"



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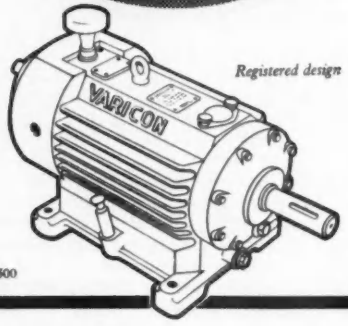

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Used coolant enters the storage tank through metal filter screens and passes through the filter paper into the centre of the drum. The filtered coolant is then transferred into the pump suction compartment to complete the filtration cycle.

An automatic system monitors the liquid levels inside and outside the drum, so that reduced filtration rates occasioned by sludge accumulation on the surface of the paper are compensated by reeling up paper on the dirty side and feeding clean paper from the feed reel, the winding process being powered by an air motor. The filter paper removes all solids larger than 4 microns and has an effective filtration surface of 190 sq ft, corresponding to a filtration capacity of 4·4 gpm of coolant per square foot of paper at maximum throughput. An agitator unit, oscillated by a geared electric motor and connecting rod, fits closely around the periphery of the drum to prevent sludge deposition at the bottom of the tank.

Heavy-Duty Oxy-Propane Flame-Cutting System

Capable of cutting a slab of carbon steel of 42-in. thickness at a rate of 10 ft per hour, a new oxy-propane heavy-duty flame-cutting system, developed by the Calor Gas (Distributing) Co. Ltd., of London, W.1, is claimed to achieve outstanding savings in costs and man-hours on all thicknesses up to 60 in.

As distinct from normal practice in British steelworks for cutting maximum thicknesses, using either oxy-acetylene alone or oxygen and a mixture of propane and acetylene, the new system, designated the Calor P4, uses a straight mixture of Calor propane and oxygen. With this system, the considerable improvement in cutting efficiency is based on mixing the propane and oxygen in the cutting nozzle, eliminating the restrictions known to occur with injector-type nozzles, in which the fuel is mixed in the barrel. Another significant factor is the successful reduction in oxygen pressures (down to 25 psi for heating and 30 psi for cutting) to levels at which the post-nozzle oxygen stream remains stable, thereby achieving a greater depth of penetration. It should also be noted that there are no controls on the cutter itself, the cutter being operated from a control panel which supplies a continuous and unrestricted flow of gases to the cutter from a point 10 to 12 ft distant, the panel being fitted with a quick-release mechanism for use in case of emergency.

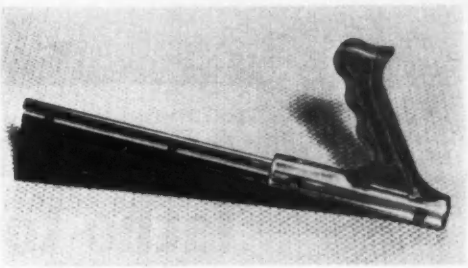
Compact Economizer Units for Small Boiler Plant

To overcome the difficulties occasioned by cramped site conditions of adding an economizer to small boiler plant with an evaporative capacity between 2,000 and 12,000 lb/hr, E. Green & Son Ltd., of Wakefield, Yorks., have introduced the "Unicorn", which is an unusually compact design of economizer in the form of a self-contained, shop-assembled unit, completely cased and insulated, with dampers and duct connections. Since these units are completely insulated, with end casing and doors to enclose the circulating bends, they are suitable for either indoor or outdoor installation, and gas flow can be either upwards or downwards without any need for modifications. The "Unicorn" is in no sense a miniature unit, but a full-sized economizer employing standard cast-iron gilled tubes and connecting bends. The diamond-shaped tube body and rectangular fins give high rates of heat transfer with low draught loss, and the tubes are easy to clean.

These economizers are designed to suit most boilers with pressures up to 650 psi, and are available in four sizes, i.e., with 12, 16, 18, and 24 tubes, giving heating surfaces of about 505, 740, 830, and 1110 sq ft respectively. Typical performance data for an 18-tube unit, based on coal firing, with an evaporation of 2000 lb/hr, a boiler pressure of 120 psi, no superheat, a feedwater temperature of 120°F, and assuming 2·5 lb of gases per pound of water, are stated to show a saving in fuel of 17% with an inlet gas temperature of 600°F, and 14% with an inlet gas temperature of 450°F. For an evaporation of 8000 lb/hr, with the other conditions unchanged, the fuel savings are 12·5% at 600°F, and 8% at 450°F.

Sheet Saws with Triangular Blades

As announced by J. Stead & Co. Ltd., of Sheffield 2, the latest addition to the Darwins Tool Division range is the "Steadfast" sheet saw, intended for cutting asbestos, plastics, wood, steel, and other materials in a wide variety of forms, including sheet, laminates, blocks, boards, tubes, and corrugations up to 1¾ in. in depth.

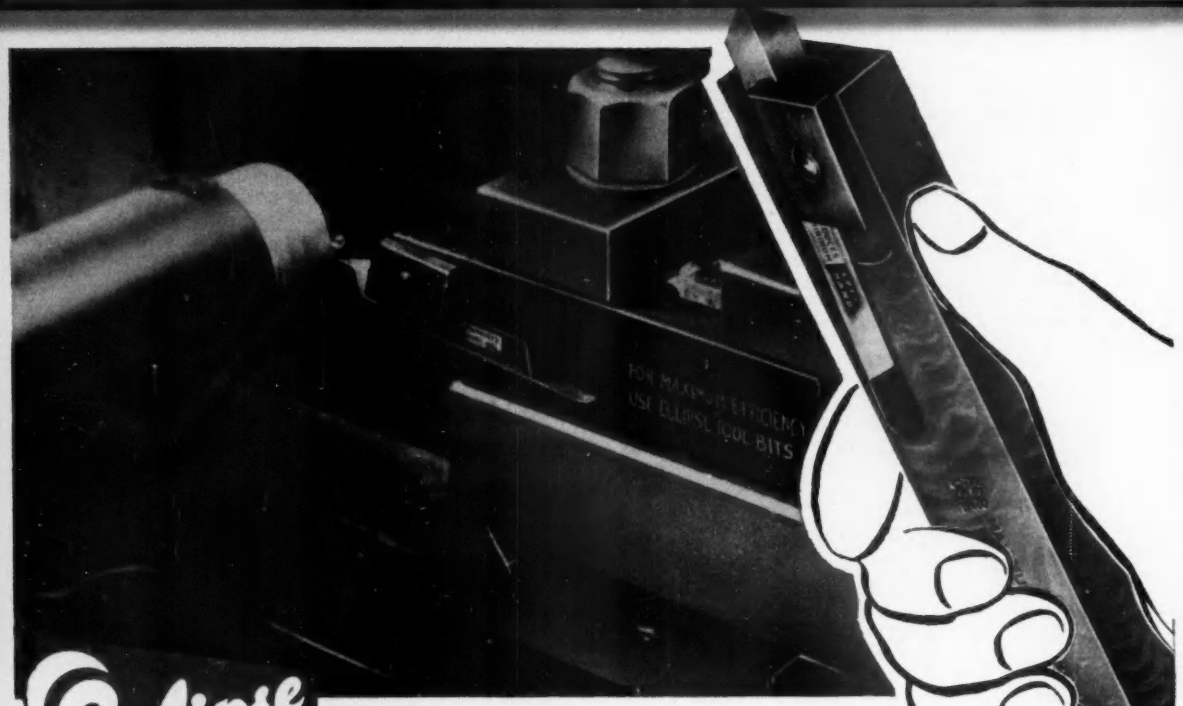


Of compact and rigid design, the saw uses special 12-in. blades of triangular shape, made of "Cobaltcrom" abrasion-resistant steel. The blade is held in a polished alloy spine to which is fitted a shatterproof amber-plastic handle, so designed as to avoid any possibility of interference with the work. Two blades, one of 14 threads per inch and the other of 24 threads per inch, are supplied, the blades being readily interchangeable by removal of four nuts and bolts. The saw gives accurate cuts and has a long blade life, while the triangular shape of the blade facilitates starting and completing cuts in tubes, etc., and also makes it possible to cut enclosed areas in sheet material without the need for preliminary "break-in".

Hydraulic Vice Jaws and Clamping Fixtures

Eliminating many of the limitations imposed by conventional vices and clamps, the range of "Hydrajaw" hydraulic vice jaws and clamping fixtures designed and manufactured by Larrad (Hydrajaws) Ltd. and distributed in England and Wales by Alfred Herbert Ltd., of Coventry, is of simple construction and employs the well-known principle of the uniform distribution of an applied pressure throughout a liquid.

The vice jaws consist essentially of mild-steel blocks, suitable for inserting into a machine vice and provided with a series of protruding plungers for gripping the workpiece. The spaces behind the plungers are filled

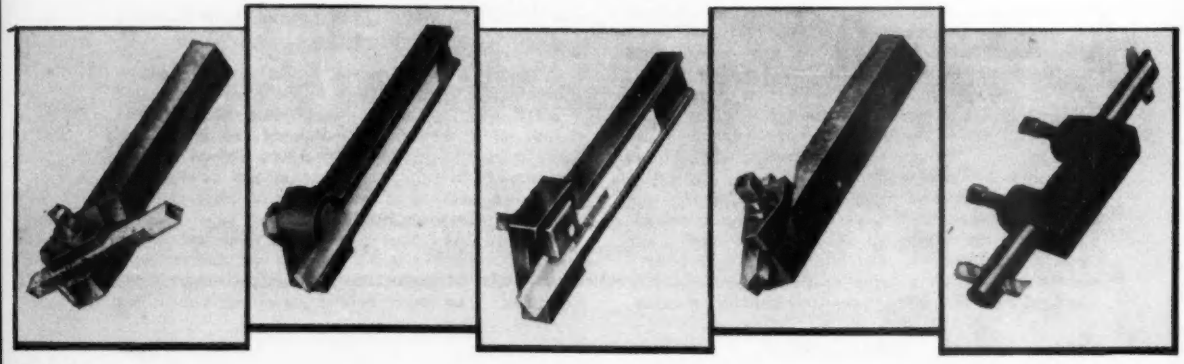


Eclipse

tool bits, lathe tools and tool holders *with many special features*

"Eclipse" tool holders are manufactured with the utmost care from high quality materials, are carefully heat treated and incorporate a number of special features which enable them to do their job superbly well.

To complete the list of tools for turning and metal cutting, there is also the extensive range of "Eclipse" tool bits and lathe tools. Made from "Eclipse" H3 cobalt High Speed Steel, these tools are carefully heat treated to give the perfect combination of hardness and toughness — tools which can be relied upon to maintain a keen cutting edge.



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with hydraulic oil and are interconnected, enabling the plungers to adjust themselves automatically to the contour of the workpiece as the vice is being closed, and also to exert equal pressure when the vice is fully tightened. In practice, it has been found that, in addition to applying equal pressures, the clamping effort of each plunger, when the vice is only moderately tightened, is greatly in excess of that applied by the vice alone. A range of eight standard "Hydrajaw" vice jaws is available with a choice of six designs of plunger heads. The smaller sizes can be supplied with matching multiple Vee-blocks, suitable for holding a number of small components, or with Vee-blocks having a single horizontal Vee.

Operating on the same principle as the vice jaws is a range of six "Hydrajaw" clamps, which resemble in appearance conventional solid jig and fixture clamps. The advantage of this type of clamp is that, in place of the normal solid clamping pads, a row of clamping plungers, again interconnected by hydraulic oil, provides fully compensated clamping, without any requirement for spherical seatings and washers. In addition, a series of "Hydrajaw" fixtures is available. In these units, pressure is applied to the fluid by means of a screwed master-plunger embodied in the unit itself; in other respects, the principle is the same, i.e., that of a hydraulically compensated, closed-circuit, multi-point clamping unit. The advantage of this unit is that irregularly shaped components or a number of small components can be held by one clamp actuated by turning a single screw, eliminating the need for a series of small clamps, each with a separate clamping screw, and thereby effecting considerable reductions in floor-to-floor times. In addition to a standard range of clamping units and fixtures, a special planer "Hydrajaw" is available, with three angled spiking-down plungers designed specifically for use on planing machines, heavy-duty milling machines, and large shaping machines.

Portable Transistorised Vibration Meter

Covering frequencies between 5 and 2000 cps, the Type–1431 transistorized vibration meter announced by Dawe Instruments Ltd., of Brentford, Middlesex, is designed to measure the three most important characteristics of vibration, i.e., displacement, velocity, and acceleration. The instrument is of compact design, measuring only $7 \times 7\frac{1}{2} \times 10\frac{1}{2}$ in. high and weighing about $7\frac{1}{2}$ lb, and can be operated either from standard a.c. mains supplies or, for use in the field, by two built-in 9-V batteries with a typical life of 150 hr.

The instrument comprises a vibration pick-up of the moving-coil velocity type, a high-gain amplifier incorporating integrating and differentiating networks, and an adjustable attenuator, together with a meter reading directly in terms of displacement, velocity, and acceleration, the required characteristic being selected by a three-way switch. The pick-up gives an output which is proportional to the velocity of the motion under investigation. This voltage is fed into the input socket of the equipment and, in the case of velocity, directly through an adjustable attenuator to a three-stage transistor pre-amplifier of high input impedance. The amplified signal is then fed through another attenuator into three pairs of transistors with local negative feedback. The output of this amplifier passes to a metering stage in which the meter is in the negative feedback line to give good scale linearity. The amplifier output also goes to a separate amplifying stage for monitoring purposes. The circuit supply voltage is stabilized in three separate sections with Zener-diode references, the gain stability of the complete circuit being exceptionally high and virtually independent of normal temperature or supply-voltage variations.

The two attenuator sections are operated by a single control switch, the later section operating first to prevent overloading of the output stage and to improve the signal-to-noise ratio of the amplifier at higher input levels. The signal from the vibration pick-up is first passed through an integrating circuit for displacement measurement, or a differentiating circuit for acceleration measurement, and is then fed into the amplifier as before. An output-jack connector to the monitor is provided so that the amplified signal can be displayed on a cathode-ray oscilloscope, or used with a suitable analyser to determine the component frequencies or the frequency spectrum of the vibration.

The Calculation of Natural Circulation in Water-Tube Boilers

(*Concluded from page 78*)

For practical calculations of driving pressure p_d, eqs. (1) and (3) give the expression

$$p_d = (\rho_w - \rho_s)\,\eta_d \frac{v_{sth}}{v_{sth} + v_{wth}} gH \qquad .. \quad (10)$$

and evaluations can be facilitated by means of a diagram such as that shown in Fig. 4, from which mean values are easily determined for any limiting values of steam velocity that may be considered. Actually, the diagram in Fig. 4 is based on test data for a steam pressure of

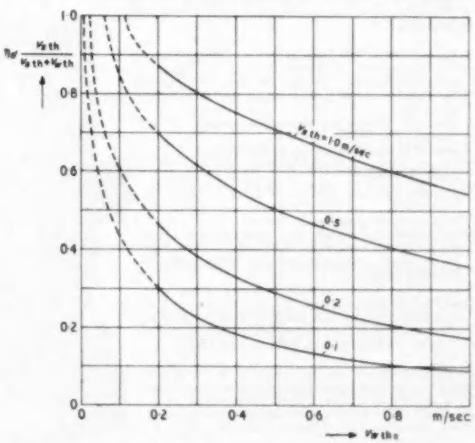


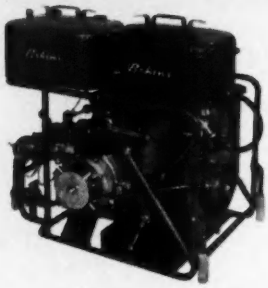
Fig. 4. Diagram for facilitating the calculation of driving pressure p_d

130 atm and for tubes of 56 mm diameter; it can, however, be used for somewhat different diameters, probably over the range from 40 to 60 mm, provided, of course, that the steam pressure is unchanged. For much larger diameters its use is less advisable, since in such cases high average relative velocities are usually obtained between the steam and the water, owing to the formation of a steam channel through the middle of the tube.

Perkins

THE MARS

50 H.P. GAS TURBINE DRIVEN WATER PUMP



In addition to its remarkable performance as a water pump, use of the turbine exhaust for de-icing and other emergency heating, drying applications—practical developments of this unit include manufacture of inert gas and improved production of foam. The Mars gas turbine, made under licence from Solar Aircraft Company, San Diego, California, U.S.A. is designed for easy hand starting even in extreme conditions. It is one of the simplest fuel burning engines ever developed, requires little maintenance and infrequent overhaul. It is compact and extremely light in weight.

- PUMP RATING 500 Imp. g.p.m. at 100 p.s.i.g. discharge pressure. 2273 litres/min. at 7.03 kg/sq.cm —for firefighting, salvage, etc., equally suitable for shipboard and land installations with fresh or sea water.
- COOLING None required—the engine is self-cooled.
- STARTING Handcrank, magneto ignition.
- OPERATING RANGE Minus 30°F to 130°F (—34°C to 54°C).
- PRIMING Ejector—compressed air supplied by the engine.
- FUELS Diesel, paraffin, Kerosene, JP1, 2, 4, 5.
- INSTRUMENTS Exhaust gas temperature pyrometer. Tachometer with hourmeter. Lubricating oil pressure gauge. Fuel pressure gauge. Water pressure gauge.
- MOUNTING None required—frame assembled unit—free of vibration.
- CONNECTIONS One-4in. suction. Two-2½ in. discharge. Threads and valves to specification.
- WEIGHT—180 lb (82kg) without fuel tanks.

Other applications of the MARS gas Turbine include:— Instructional Sets, Electric Generating Sets, Auxiliary Power Units, Compressor Sets, Bleed Air-requirements, De-icing, Packaged Power Plant, Process needs of Heat and Power.

THE SATURN

750 KW T 1000 GAS TURBINE GENERATING SET

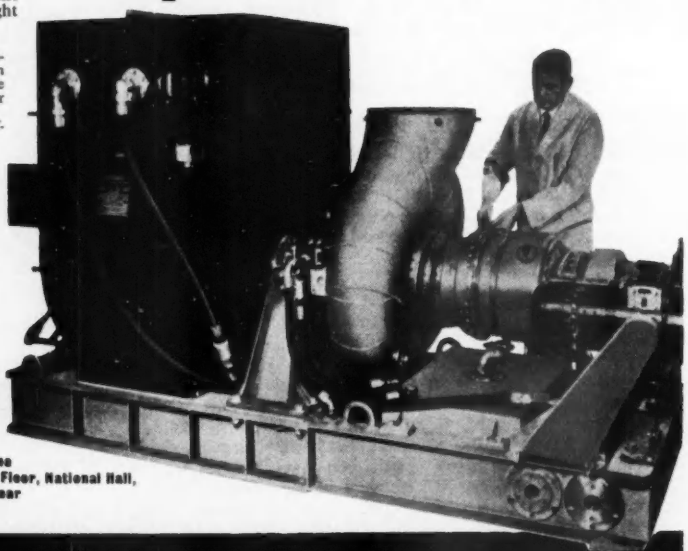
The SATURN Gas turbine is one of the most advanced engines of its type ever developed to give a thermal efficiency of 22% in simple open cycle form. Push button starting is automatically sequenced, the engine reaches full power in a maximum of 40 seconds even in extreme climatic conditions and after long periods of standby service, thus saving valuable time and fuel wasted with conventional plant. Vibration problems are eliminated, a foundation is not necessary and installation costs are low. The engine can be operated by relatively unskilled personnel. Simplicity of design and accessibility of components facilitate maintenance. Few moving parts and an air cooling system assure dependability.

Other applications include

PUMPS Salvage, flood control and product pipe line pumping are ideal requirements for the SATURN gas turbine. Compact and lightweight, the engine is equally suited for mobile equipment.

COMPRESSORS Direct drive of 20,000 r.p.m. is available for use with the latest designs of high speed air and gas compressors. Reduction gearing can therefore be eliminated to reduce first cost and maintenance.

MARINE PROPULSION The two shaft variable speed version provides a "torque-converter" effect giving quicker acceleration, better manoeuvreability and positive emergency stops. This has particular appeal for hydrofoil craft to overcome "hump" resistance.



See Perkins Diesels, Gas Turbines and Marine Outboards on Perkins Stand No. 9, Row M Ground Floor, National Hall, at the Engineering, Marine Welding and Nuclear Exhibition, Olympia.

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ADDITIONAL ABSTRACTS

Continuous Direct X-Ray Inspection of Welds

By S. T. NAZAROV
From *Zavodskaya Laboratoriya*, Russia,
Vol. 26, No. 11, 1960,
pp. 1229–1232, 3 illustrations.

AN important step towards the automation of X-ray inspection of welds is the production of an image suitable for continuous direct examination; thus eliminating the laborious and lengthy taking and developing of radiograms. Equipment developed in Russia is stated to achieve this objective by using an image intensifier, whose image can either be examined directly or on a television screen.

In this equipment, the X-ray beam passes through the weld under inspection and the glass wall of a tube, exciting the luminescence of a fluorescent layer applied to a thin aluminium screen. The image obtained on this screen is similar to that of a conventional X-ray screen. The incident light releases electrons from a photocathode applied directly onto the aluminium screen. The number of electrons released is directly proportional to the brightness of the screen, i.e., to the intensity of the beams, so that the fluorescent image becomes an electronic image.

The high-energy electrons (25–30 kV) released from the cathode stream towards an observation anode screen, producing an image on it. This image is from 7 to 9 times smaller than the image on the aluminium screen, so that the electrons are concentrated on an area of from about 50 to 80 times smaller, with a brightness which is very much greater than that of the original screen. The image on the observation anode screen is then examined through an optical system with a magnification of from $\times 9$ to $\times 7$, thus producing an image of the original size. All transmission processes are linear and therefore do not affect the contrast of the original image. As the final image is produced by electrons, the grain size does not affect its quality.

Equipment constructed for testing this inspection system under workshop conditions consists of a carriage for the workpiece and an arm supporting the X-ray tube. The image intensifier is mounted on top of the inspector's cabin, from which operation of the X-ray equipment and of the image intensifier is controlled. The image can be observed optically or on a television screen, but fluctuations in mains voltage cause an instability of the television image, rendering this method from 10 to 15% less sensitive than direct observation on the image-intensifier screen, on which defects such as pores, cracks, and inadequate fusion are detected with the same reliability as on radiographic film. The best speed for the inspection of magnesium alloys was found to be from 0·5 to 1 m/min, and the increase obtained in speed of inspection was considerable in all tests. As the next step in this development, it is intended to replace the very tiring direct observation of the image by recording it on a video-recorder tape through a television system. This scheme has the advantage, compared with direct recording from a television screen, of working with a wider frequency range of light signals.

The Assessment of Filler Metals and Fluxes

By G. M. A. BLANC, J. COLBUS, and C. G. KEEL
From *Welding Journal*, U.S.A.,
Vol. 40, No. 5, May 1961,
pp. 210s–222s, 17 illustrations.

REQUIREMENTS for technical solders and fluxes are largely set up empirically, and there is no certainty as to the meaning of important physical values, such as the surface tension, viscosity, etc. of filler metals and fluxes. By way of contrast, the concept of "wetting power" is largely indeterminate, and little is known of the relationship existing between the individual factors. Recent research has shown that the physical values of surface tension and viscosity of filler metals and fluxes indicate little in brazing technology, and thus have no significance. Accordingly, attempts have been made to give preference to other characteristics, such as "spreading" (wetting), since they can give indications which accord more closely with practice.

This survey adds something to this work, and deals with the physical meaning of the surface tension of filler metals and fluxes and gives the results of new experiments, as well as presenting the new technical concepts, such as wetting power. In addition, indications are given of several interesting relationships between the characteristic values mentioned above, which are important for both theory and practice.

Some of the conclusions derived from this survey can be summarized as follows:—

(1) The physical concepts of the surface tension of filler metals and fluxes do not appear to indicate generally valid and unequivocal amounts and values in brazing technology since, by definition, they are only measured in air.

(2) The experimental measurement of the surface tension of filler metals and fluxes was found difficult. Further research is necessary.

(3) Moderate quantities of dissolved substances can have a favourable effect on the tensile strength and wetting of filler metals. Further systematic study of these problems would be helpful.

(4) Neither surface tension nor viscosity is the decisive factor in the wetting of a filler metal. In addition to the characteristics and quantity of the flux used, the decisive processes are principally those taking place on the boundary area between the filler metal and base metal. Further research is needed to understand this "interfacial tension".

(5) A definite relationship exists between the viscosity of borax/boric acid mixtures and wetting, since the spread is reduced as viscosity increases.

(6) With an increase in the viscosity of powder

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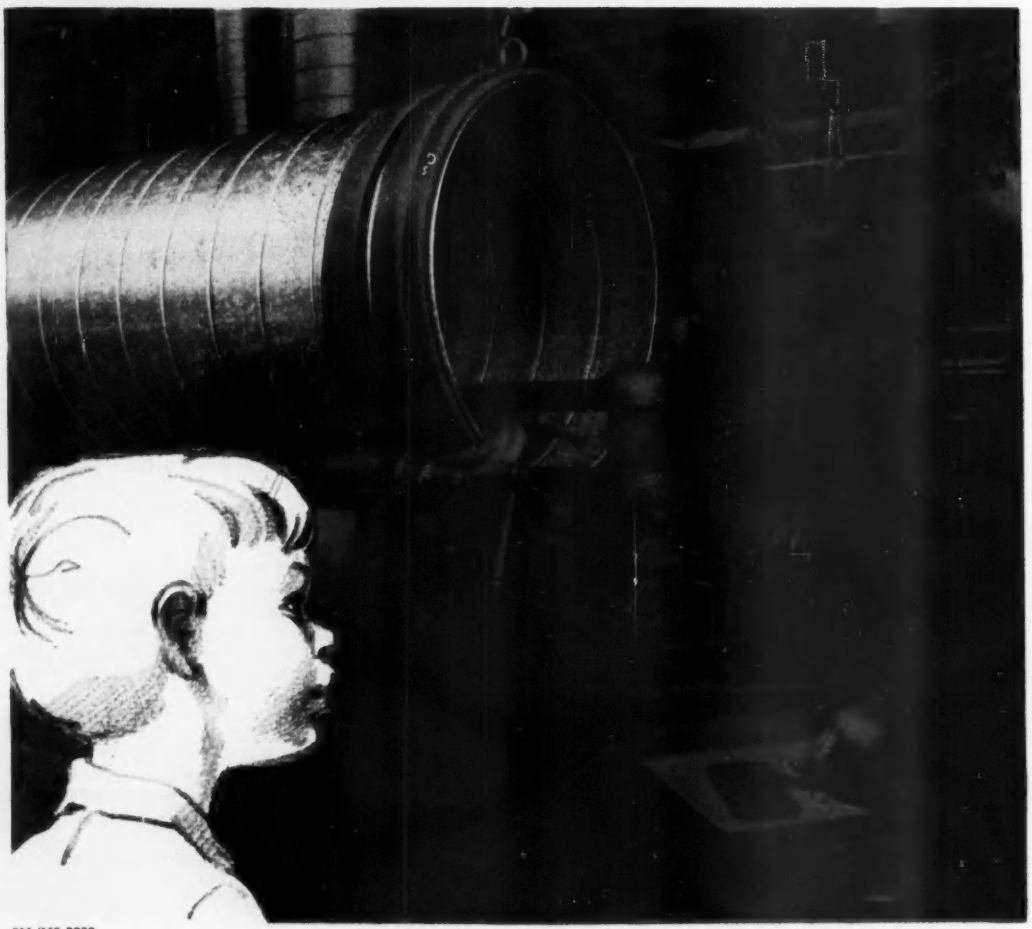

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fluxes and a reduction of the spreading area, the tensile strength of gap-brazed joints is reduced; alternatively, tensile strength increases with a rise in wetting through the flux. When using aqueous paste fluxes, maximum values for wetting can be obtained, and these provide the peak values for tensile strength.

(7) The relationships are different with braze welds, as tensile strength seems to increase in conjunction with the increase in the flux viscosity.

(8) On steel the contact angle of copper and filler metals drops as temperature rises, i.e., wetting power is increased. This is not the case with cast iron, i.e., the contact angle remains virtually constant.

(9) Tests indicate that the importance of flux in wetting and tensile strength is as great as that of the filler metal.

The Remote Control of Cooling-Tower Fans

By R. J. Davis
From *Power Apparatus and Systems (A.I.E.E.)*, U.S.A., No. 52, February 1961, pp. 1202–1205, 4 illustrations.

Where cooling towers are used for condenser cooling, cooling-tower fans account for a significant part of the station auxiliary power. For large steam-turbine installations, the amount of electric energy required by the fans is of sufficient magnitude to justify expenditure to minimize energy consumption. A customary method used to reduce the energy consumption on large installations is to operate only the optimum number of fans. Remote control is normally provided to permit operators conveniently to start and stop fans from the central operating area, as required by changes in operating conditions or as turbine loading varies.

Cooling-tower performance is affected by such variables as the amount and configuration of wetted surfaces, wet-bulb temperature, heat load, and the flow of cooling water and of tower air. It is possible to change the amount of wetted surface by cutting out tower cells during operation, but this is not recommended, as intermittent wetting and drying of the wooden surfaces will decrease tower life. The only feasible variables which can be controlled by the operator to conserve electric energy are the flow of cooling water and of tower air. Minimum tower operating costs will be achieved when these flows are regulated in such a way that, for a given set of operating conditions, the nett kilowatt output is a maximum.

This paper describes the details of a cooling-tower installation which uses a code-selector supervisory system for the remote control of individual fans from the main control room. It is pointed out that conventional control-system investment costs vary directly with circuit length, while supervisory system costs increase very little with circuit length. Consequently, there is an "equal-cost" point where a supervisory system should be considered. As circuit lengths increase beyond this point, conventional control costs quickly become excessive. With the present trend towards automation in power stations and the application of control computers to accomplish boiler-turbine start-up and operation, there may soon be a need to extend this automation to condenser cooling-water control. In this case, a supervisory system can be applied to accomplish the control and to transmit whatever data may be required.

Plasma Synthesis and its Application to Thermionic Power Conversion

By K. G. Hernqvist
From *RCA Review*, U.S.A., Vol. 22, No. 1, March 1961, pp. 7–20, 11 illustrations.

One of the major problems associated with the thermionic energy converter is that of overcoming the effect of inter-electrode space charge in hindering the flow of electrons from the cathode to the anode. This problem of space-charge cancellation is not unique to the thermionic energy converter, but is common to high-current electron-tube devices for rectification and switching purposes. An excellent way of overcoming space-charge effects is to introduce positive ions in a quantity sufficient to neutralize the electronic space charge. The inter-electrode space then becomes occupied by electron-ion pairs, i.e., a plasma.

In conventional gas-discharge devices such as the thyratron, the plasma is generated by electron impact on neutral gas atoms. A much more efficient method of plasma generation, one that is suitable for the thermionic energy converter, is that of plasma synthesis. Here, ions and electrons are generated separately and brought together to form a plasma, in contrast to the method of direct electron-ion pair generation.

In the type of plasma synthesis discussed in this paper, the electrons are thermionically emitted from the cathode. The ions are generated by resonance ionization of caesium vapour at a hot, high-work-function metal surface. Three cases of plasma synthesis suitable for different cathodes (and heat source for temperatures) are discussed. In one case, both ions and electrons are generated at a high-work-function surface. In another case, a multi-work-function surface is considered, where electrons and ions originate at different points on the cathode surface. In the third case, electrons and ions originate at separate sources, and experimental results for this last method of plasma synthesis are described, using an experimental tube with a power output of about 0·55 W/cm² at a cathode temperature of 1100°C. The experimental tube utilizes a third electrode, introduced solely for generating ion space-charge neutralization. This plasma triode does not require any critical spacings and is suitable for the heat-source temperature range from 1000 to 1500°C. This temperature range has, until now, been reserved for the close-spaced vacuum-diode converter, which is difficult to fabricate because of the critical tolerances. Thus, although much work still remains in geometry and materials optimization for the plasma triode, no fundamental obstacle now exists in making an efficient, rugged thermionic converter for this temperature range.

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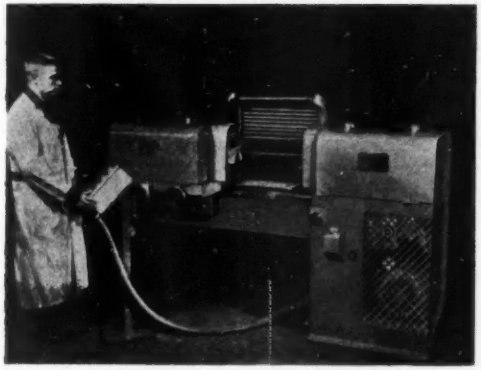
New Materials, Processes, and Equipment

Double-End Finishing Machine for Rods and Tubes

Specially constructed for high production, accurate workpiece-length tolerances, and maximum flexibility in the simultaneous finishing of both ends of tubes, rods, and similar workpieces, the new Model 666 double-end finishing machine developed by the Pines Engineering Co., Inc., of Aurora, Ill., is completely automatic. Typical operations include inside and outside deburring, chamfering, facing, and other light forming or pointing work, the workpieces being automatically fed into the machining position by a hydraulically actuated "Chute-Matic" feed mechanism which can hold length tolerances to within 0·005 in. on a production basis.

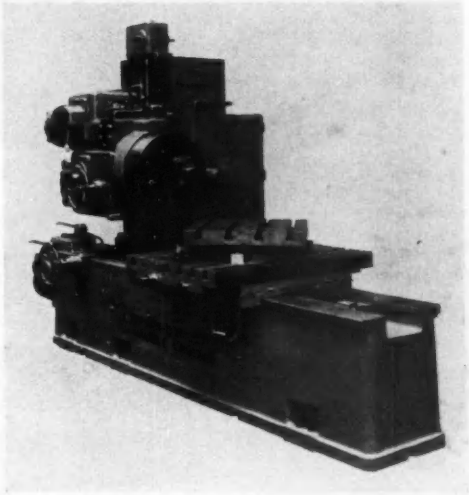


The machine can produce from 2400 to 3000 finished ends per hour and can handle workpieces from $\frac{1}{2}$ to 3 in. diameter in lengths up to 60 in. with the standard-bed machine, or up to 120 in. with the extended-bed version. The normal minimum workpiece length is 5 in., but adaptors are provided to accommodate work as short as $2\frac{1}{2}$ in. Solid stock can be chamfered or pointed in diameters down to $\frac{1}{4}$ in. Set-up is effected easily and simply by means of individual push-buttons, set-up time being further reduced by the application of tool-holders and easy adjustment of the "Chute-Matic" feed. Precision adjustment for material length is accomplished by the use of a single hand-crank, while infinitely variable spindle feeds can be selected by a simple handwheel.

The machine consists of three basic units, i.e., the base and stationary head, the machine bed, and the movable head. The automatic "Chute-Matic" feed is sectioned, one section being an integral part of the stationary head, and the other an integral part of the movable head, providing automatic adjustment of the feed mechanism with the setting of the movable head to accommodate specific work lengths. Workpieces are loaded into the "Chute-Matic" feed, and hydraulic transfer mechanisms strip them from the feed, delivering them to the machining position. After machining, the workpiece is ejected downwards into a receiving pan. Rapid approach, controlled feed, and rapid return of the spindles are actuated by hydraulic cylinders operating through a rack-and-pinion mechanism, positive stops on both advance and return ensuring close-tolerance lengths.

Horizontal Facing, Boring, and Turning Machine

Capable of being operated by semi-skilled labour, a horizontal facing, boring, and turning machine recently introduced by A. Kitchen-D. Walker Ltd., of Halifax, is specially designed for work on pipe flanges, valve bodies, and similar circular components. The main table measures 42 × 30 in. and has 36 in. of power traverse, forward and reverse, along the main bed, with three rates of power feed, i.e., $\frac{1}{2}$, 1, and $1\frac{1}{2}$ ipm, and three rates of rapid traverse, i.e., 24, 48, and 72 ipm; in addition, a handwheel is provided for fine adjustments, together with a manual cross adjustment of 30 in. The squaring table, which is optionally available in sizes of 24-in. or 30-in. square or circular, has four definite 90-deg. positions and has a lift motion to break the joint faces and to permit an easy spin-round movement on ball bearings. This table can be removed as a unit to leave the main table clear. Double locks to the tables and head ensure rigidity of the machine under heavy-duty conditions.



The main drive is from a $7\frac{1}{2}$-hp constant-speed motor through a gearbox which gives nine faceplate speeds, ranging from 17 to 216 rpm, the final drive being by helical gears. At any speed when the stop-button is pressed, the facing head comes to rest in a few seconds, completely free from shock. The facing slide has two rates of automatic feed, i.e., $\frac{1}{32}$ and $\frac{1}{16}$ inch per revolution, forward and reverse, with automatic cut-off at the limits

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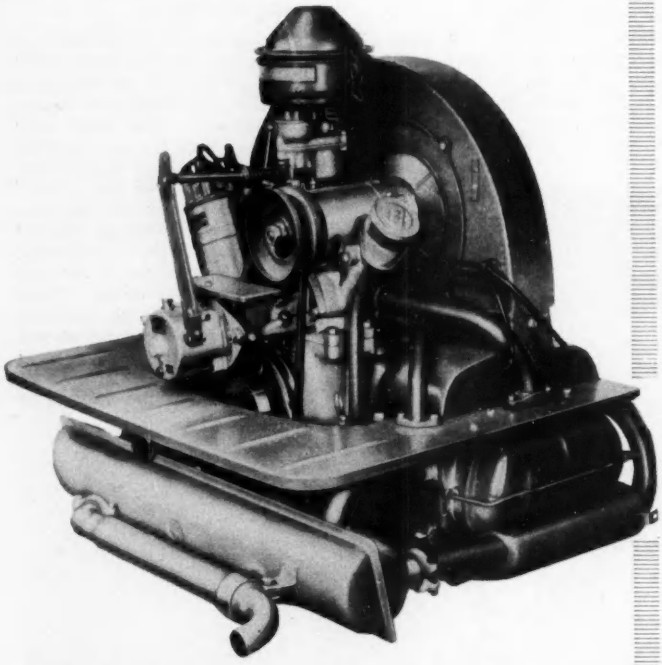

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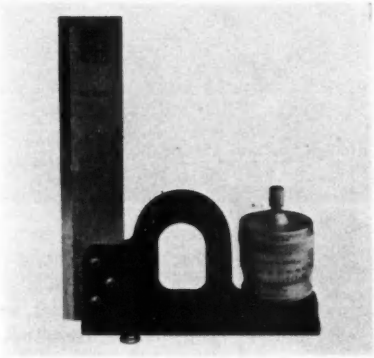
of travel. In addition to power feeds, the facing slide can be adjusted, whether rotating or stationary, by a handwheel, a micrometer dial being provided for precise adjustments. Lubrication to all gears and bearings is by means of built-in oil pumps, a one-shot system being provided for the table slideways.

Adjustable Square

Differing from conventional squares, which show an error in squareness but not its amount, the new No. 420/6″ adjustable square introduced by Moore & Wright (Sheffield) Ltd., not only shows if there is an error in squareness, but also indicates by means of a micrometer reading the actual error in squareness at the top of the blade.



In the new square, the hardened-steel blade, which is precision-ground all over and lapped on the bevel edge, is arranged so that it can pivot on hardened studs at the front of the base of the tool. In operation, the tool is used on a surface plate or a similar accurate surface, the micrometer head reading zero when the blade is truly square. If any error in squareness is noted in the component being checked, rotation of the micrometer, the thimble of which is graduated in divisions of 0·0002 in., causes the base to tilt. When the blade contacts the surface of the component all the way up, the error in squareness can then be read off directly from the micrometer head.

Automatic Shut-Down Valve for High-Pressure Systems

A new automatic shut-down valve, designed by I.V. Pressure Controllers Ltd., of Isleworth, Middlesex, can be fitted into any high-pressure pneumatic or hydraulic system to safeguard personnel against injury and to avoid damage to equipment as a result of a break in the system or of any sudden pressure variation. The valve shuts off the system whenever a minimum or maximum permissible pressure is exceeded or whenever a sudden variation in pressure takes place, e.g., through pipe breakage, malfunctioning of the system, incorrect fitting, or careless disconnection.

The valve, which has a maximum working pressure of 4000 psi and a minimum of 100 psi, basically consists of a dome-like top chamber and a lower valve assembly, the dome being separated from the valve by a diaphragm which is sensitive to pressure variations and which is in direct contact with a poppet head valve. Variation in the pressure differential across the diaphragm pushes the poppet head valve onto the valve seat, thereby closing off the passageway through the valve. The valve can be opened again by means of a small by-pass valve built into the side of the body. The closing time is about 0·7 sec. Although the valve, which can be used at temperatures between 14 and 150°F, closes virtually instantaneously when subjected to sudden surges, it still allows normal flows to pass through during normal functioning of the system.

Differential Polarographic Analyser

The new "Nashton" differential polarographic analyser produced by Nash & Thompson Ltd., of Tolworth, Surrey, is a production version of the equipment originally developed by the U.K. Atomic Energy Authority and can be used as a high-sensitivity analytical tool for many kinds of chemical and metallurgical investigations, including soil analysis, studies of the oxygen content of blood plasma, determination of the inorganic constituents of water, minerals, paint pigments, etc., the analysis of some organic substances such as dye-stuffs, and the detection of impurities in foodstuffs. In this latter application, the instrument can identify traces of metals in concentrations as low as 0·02 ppm and can carry out quantitative analyses with an accuracy of ± 1 to $\pm 2\%$ in solutions containing 1 ppm of the substance being investigated.

The new instrument uses two identical polarographic cells, which can be used separately or together, synchronizing devices ensuring that both mercury-drop cathodes grow and fall simultaneously during twin-cell operation. The height of each mercury reservoir is adjustable by means of a vernier, and the two capillaries are made from one piece, cut into two parts. These precautions ensure that the two droplets of mercury have precisely the same rate of growth. Simultaneous dropping of the mercury is effected every seven seconds by means of an electrically controlled solenoid. The two cells are housed in an

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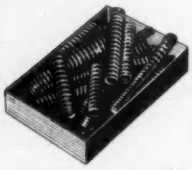

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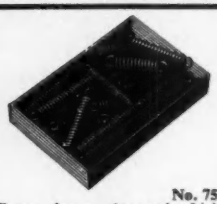

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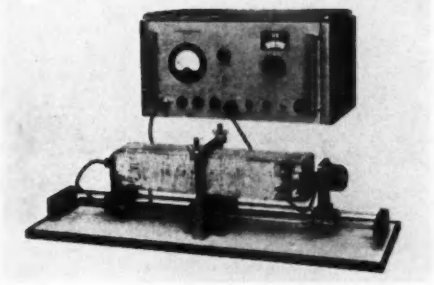
airtight perspex chamber, through which a flow of nitrogen is maintained. Nitrogen is also bubbled through the cells themselves before a determination is carried out, to eliminate any effects due to dissolved oxygen in the solution. The cells are fed through tap-funnels by vacuum suction, so that the working solutions can be removed or replenished without opening the chamber. Mercury can be drained from the cells by means of a separate tap.

The new analyser is claimed to have a greater maximum resolving power than a conventional cathode-ray polarograph and to be from 7 to 10 times more sensitive in single-cell operation, mainly because of the provision of "base-line slope compensation", whereby residual currents due to earlier reductions can be cancelled by the application of a small opposing current with a maximum value of 0·1 mA. With two cells, the instrument is from 1 to 50 times more sensitive in derivative operation, depending on the resolution required, and about 11 times more sensitive by the subtractive method. Specially purified reagents are not required. In comparative polarography, determinations with a coefficient of variation better than 0·2% are possible.

In derivative operation, the trace approximates the first algebraic derivative of the current wave-form for a single cell. Time-constant networks of 0·01 or 0·03 sec can be used to obtain derivative displays of the wave-forms produced in single-cell, subtractive, or comparative operation, and second derivative traces in derivative operation. The shorter time-constant is used when the highest resolving power is required, the peak heights obtained with maximum sensitivity being about 8 times greater than those with a conventional cathode-ray polarograph. With the longer time-constant, the peak heights are about 20 times greater.

Non-Destructive Tester for Deriving the Elastic Constants of Materials

A new non-destructive tester, announced by Cawkell Research & Electronics Ltd., of Southall, Middlesex, a member of the Simms Group of companies, provides a convenient method of deriving the elastic constants of regularly shaped specimens of materials by measuring their resonant frequency. Thus, if a specimen of known dimensions and density is vibrated longitudinally, its dynamic modulus can be found, while torsional vibration enables its modulus of rigidity to be determined. From a knowledge of both these moduli, Poisson's ratio can be found. By measuring the width of the resonance curve at which the amplitude of oscillation has fallen to $1/\sqrt{2}$ of its maximum, the damping of the specimen can be obtained. It is true that the resolution of the measurement of frequency normally prevents this latter quantity from being measured on lightly damped specimens by this method, but a special range of damping-constant meters is available for such materials.



Essentially, the instrument, designated the Type SCT4 Electrodynamic Materials Tester, is a convenient laboratory unit for determining the resonant frequency of regular shaped specimens, and consists of an accurately calibrated oscillator, which can be coupled to a moving-coil vibrator for excitation of the specimen, and an amplifier feeding a meter which measures the signal from a piezo-electric crystal type of pick-up in contact with the vibrating specimen. The tester, which covers frequencies from 100 cps to 10,000 cps with a calibration accuracy of ±0·1%, can be used with a wide variety of materials, ranging from concrete to metals, and is eminently suitable for studying property changes such as those resulting from heat treatment, irradiation, attack by acids, or frost damage.

Fabrication Studies of Columbium-Alloy Sheet

(*Concluded from page 88*)

results, maintaining a 40 to 60 r.m.s. surface finish. A minimum amount of tool wear (0·002 to 0·005 in.) was encountered at these speeds. High speeds caused cutter burn-out and work-hardening of the material.

During drilling, D-31 is similar to austenitic stainless steel in its tendency to work-harden, but drill life is slightly lower than might be expected for stainless steel. D-31 tends to pick up on the tool at various milling speeds and feeds, producing a poor surface finish, but this can be improved if a trichloroethane cutting-fluid is specified.

The limited amount of bend-testing that it was possible to carry out precluded the determination of a minimum bend radius. Specimens of sheet, 0·04 in. and $\frac{1}{32}$ in. in thickness, were bent over different radii, ranging from 1 to 5½ times the thickness, and in no instance did a bend specimen fail catastrophically, while no splitting of the materials or cracks through the thickness were observed. However, bends in the $\frac{1}{32}$-in. sheet made over a radius of $\frac{1}{32}$ or $\frac{1}{16}$ in. produced a finish with an unacceptable "orange-peel" surface. Surface finish was improved by increasing the radius to $\frac{3}{32}$ or $\frac{1}{8}$ in., but orange-peeling was not eliminated completely.

A specimen of 0·04 in. thickness was then mechanically polished and tested. Prior to bending, macroscopic examination revealed a minute network of surface fissures on the polished surface. After bending over a $\frac{1}{4}$-in. radius, a coarse surface finish was again obtained.

No forming could be done with the amount of material available, and forming parameters were obtained by constructing theoretical formability curves from mechanical-property data. Subsize tensile specimens, tested at room temperature, gave information used in constructing curves for contour stretch forming, rubber stretch-flange forming, and rubber shrink-flange forming.

Comparisons of the curves obtained for rolled D-31 sheet in the stress-relieved condition with those for 7075-W aluminium-alloy sheet showed that the D-31 sheet has forming characteristics approaching those of the 7075W sheet, which is known to possess excellent formability in the as-quenched temper.

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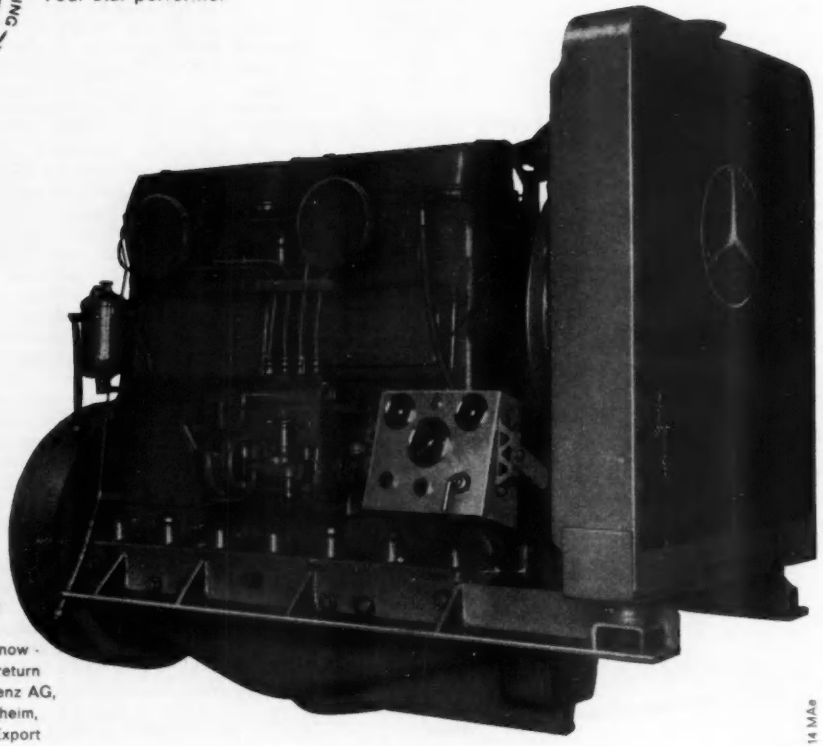
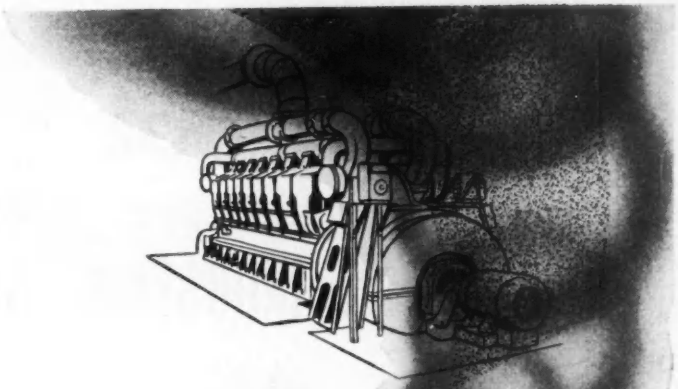
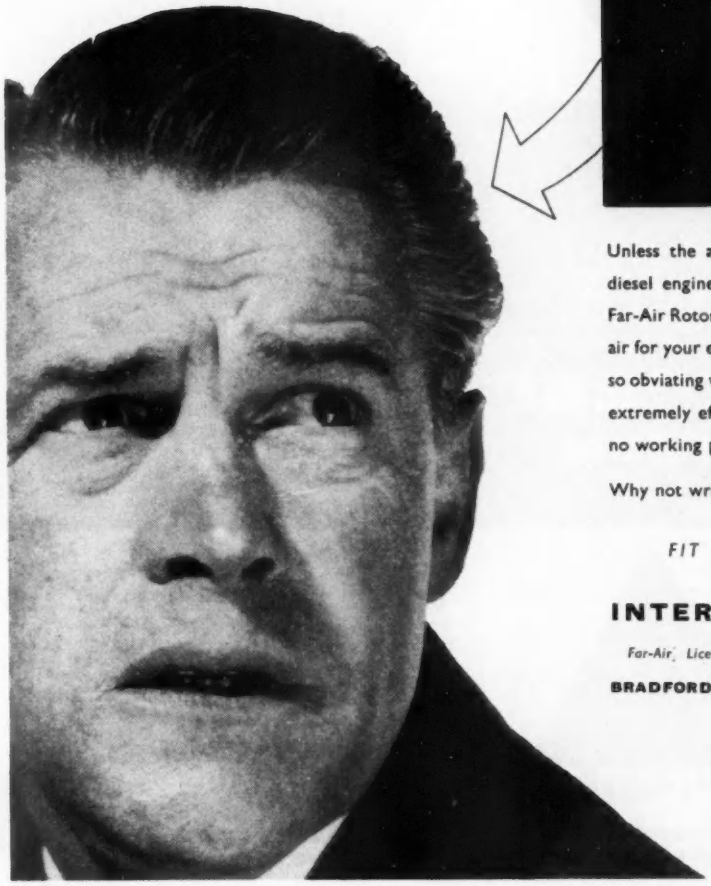


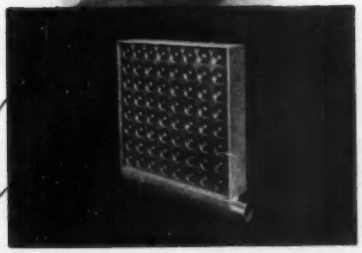
Our technical literature MX 11 will give you full particulars. Write for it now - and we'll reply by return of post. Daimler-Benz AG, Stuttgart-Untertürkheim, Verkauf Motoren/Export

14 MAe



this engine is being SABOTAGED





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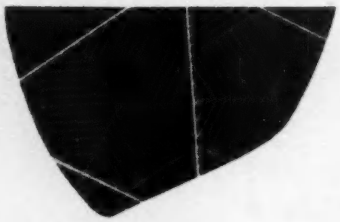
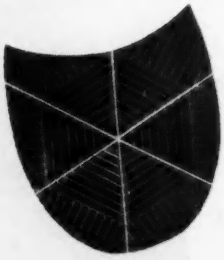
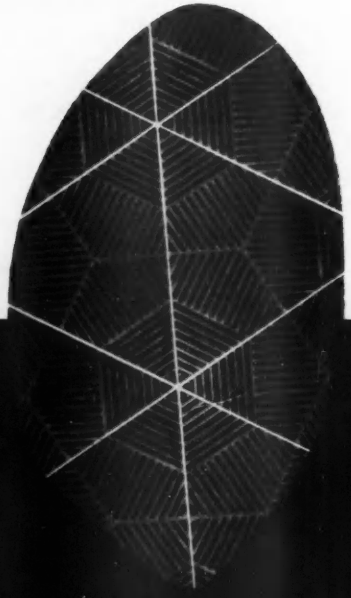


Basic steps to INDUSTRIAL SAFETY





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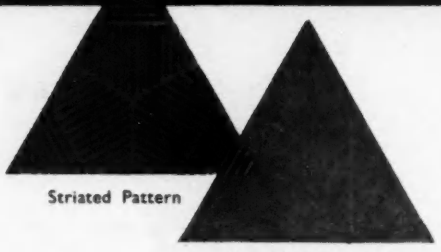
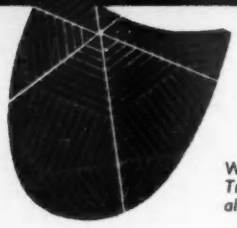


Striated Pattern

Plain-Surface Pattern



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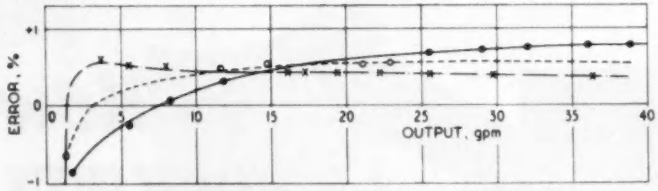
As an example, the results obtained with one of our Aviation Series RAD 64 automatic flowmeters are given in the graph, which is based on measurements by weight for three different densities. In no case does the error exceed 1%.



Solid line :- Average specific gravity = 0·716
Dotted line :- Average specific gravity = 0·765
Chain-dotted line :- Average specific gravity = 0·816

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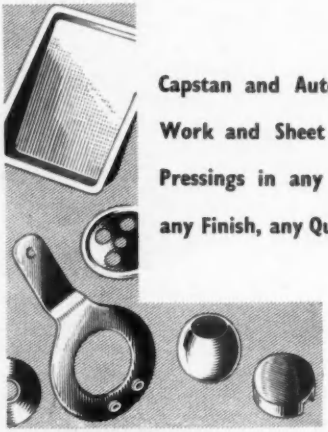

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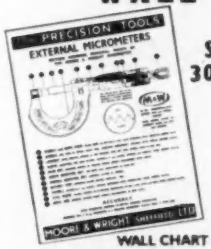
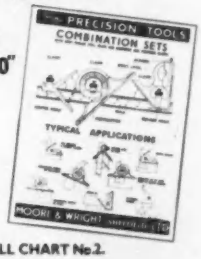


SIZE 30" x 40"



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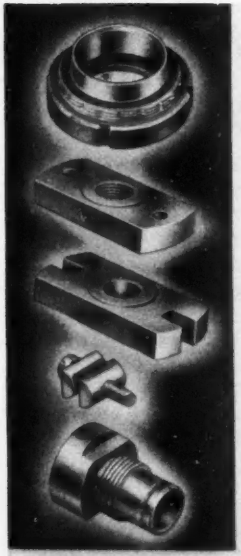

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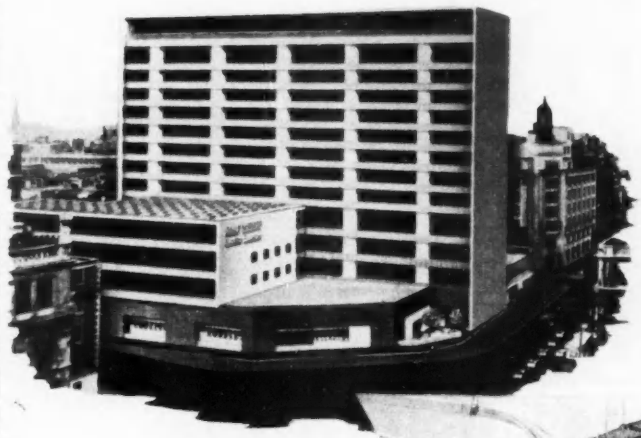
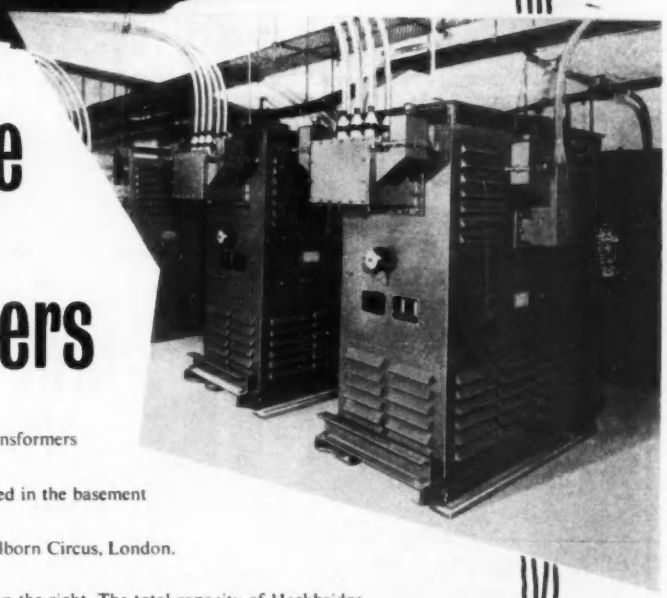


Artist's impression of the new Daily Mirror building at Holborn Circus.



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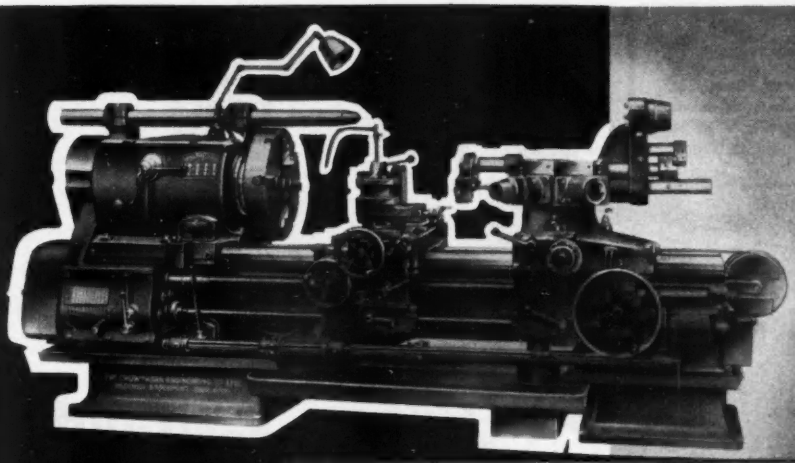

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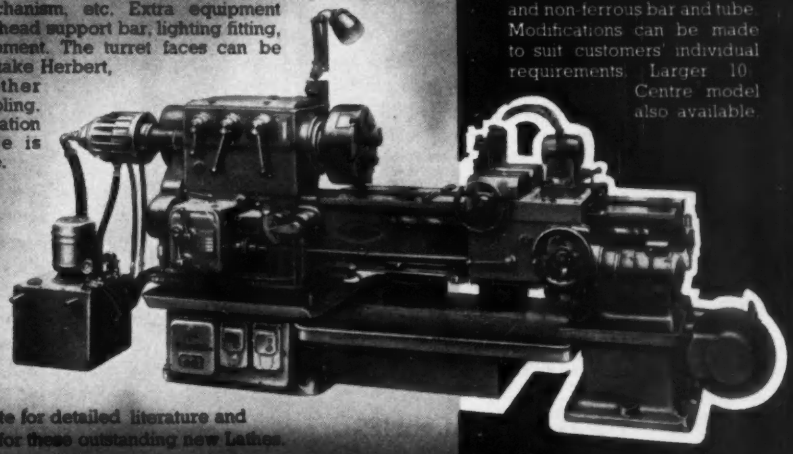

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(*T. H. Higson, Borough Engineer.*)

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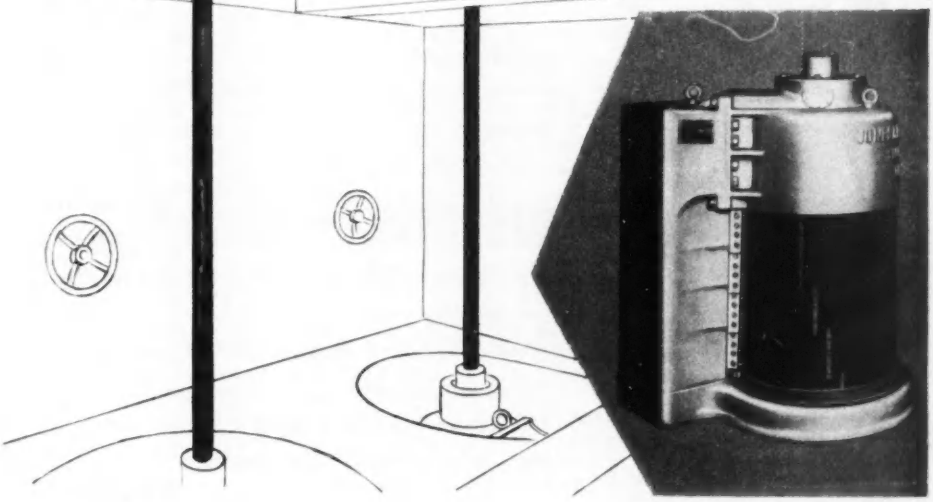

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Dimensionally stable tool steels

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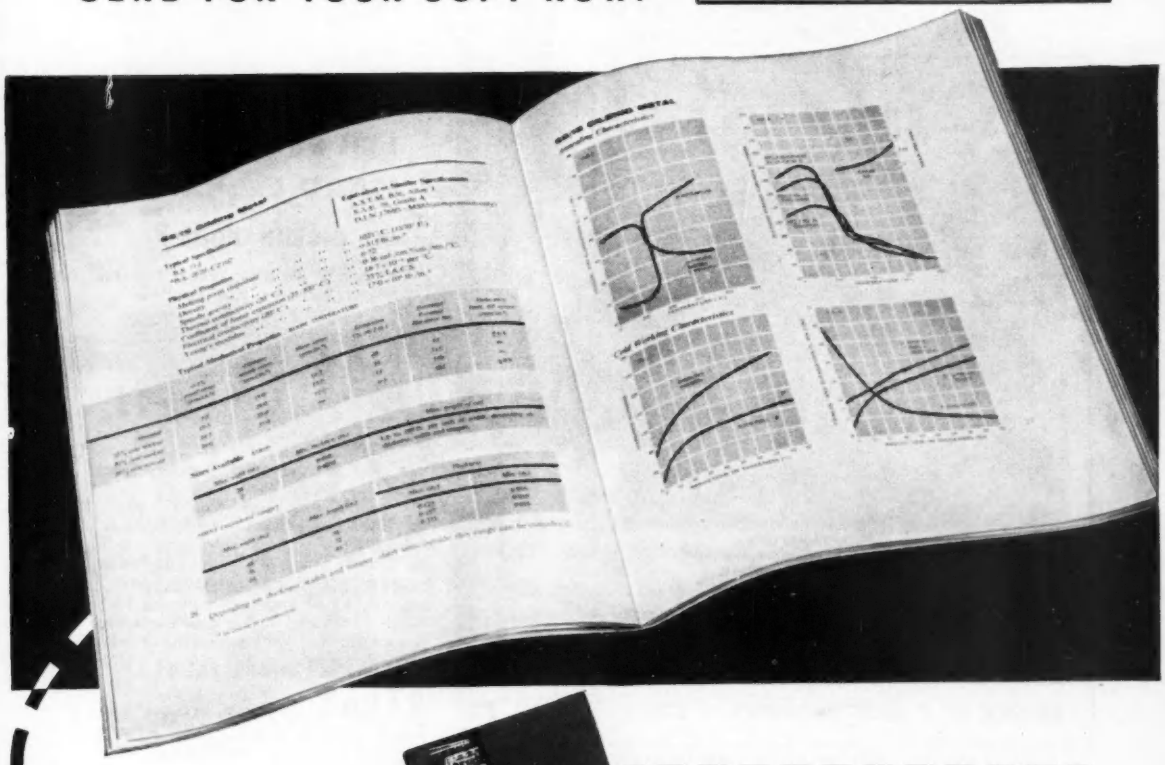

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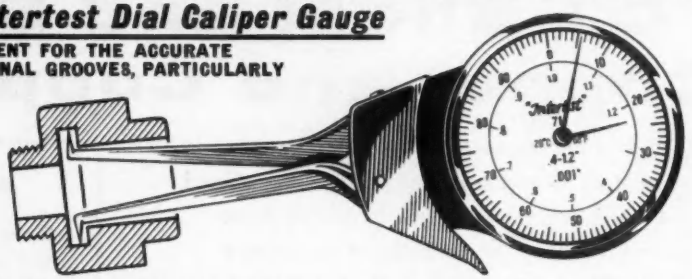

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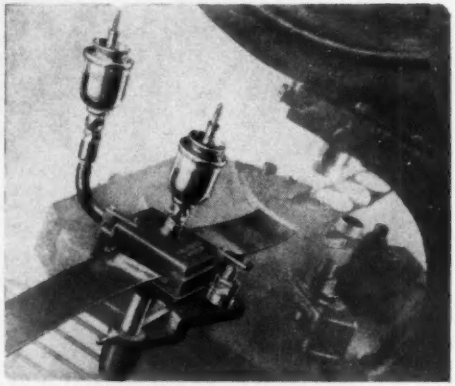

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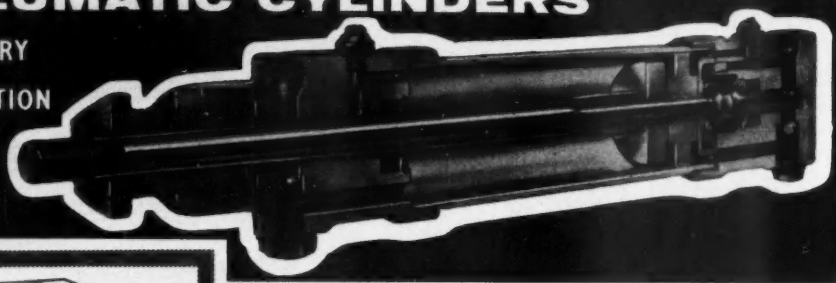

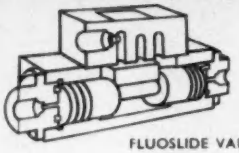

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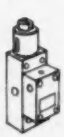

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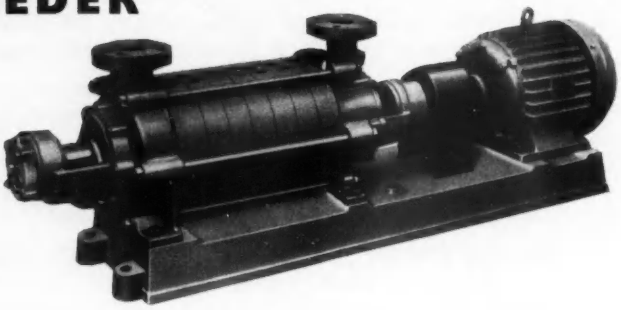

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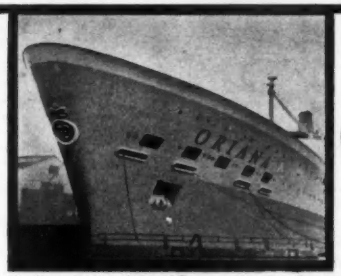

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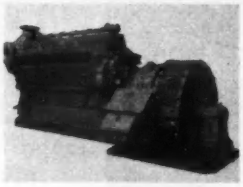

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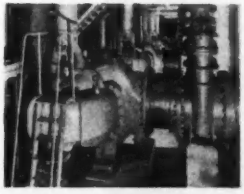

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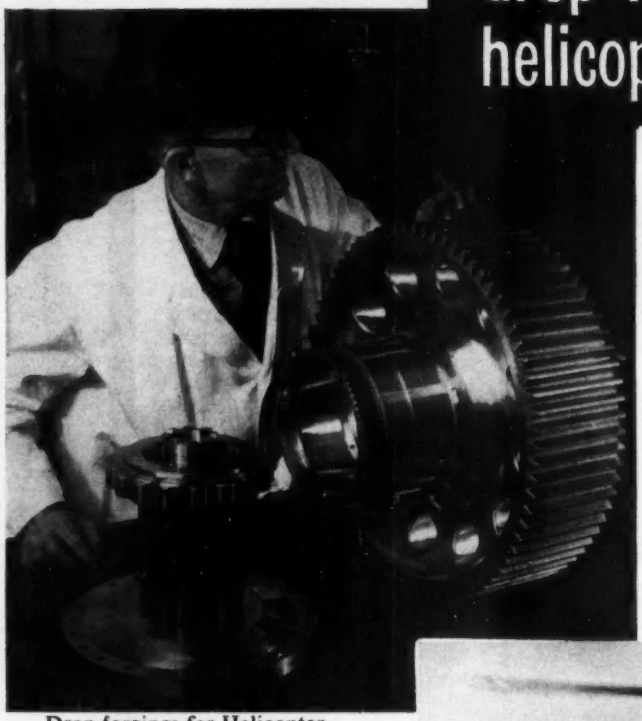

The main gear wheel and hub assembly of the Bristol type 192 twin-engined, tandem-rotor helicopter being measured to an accuracy of ·0001. Reproduced by courtesy of Westland Aircraft Ltd.

A view of the P531 turbine powered helicopter by courtesy of Westland Aircraft Ltd.

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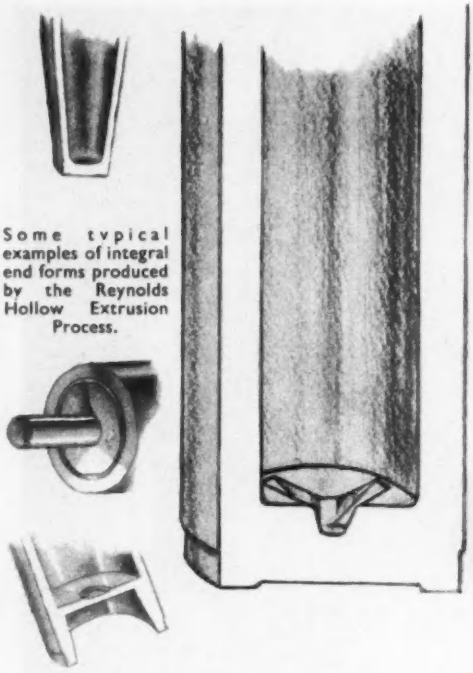

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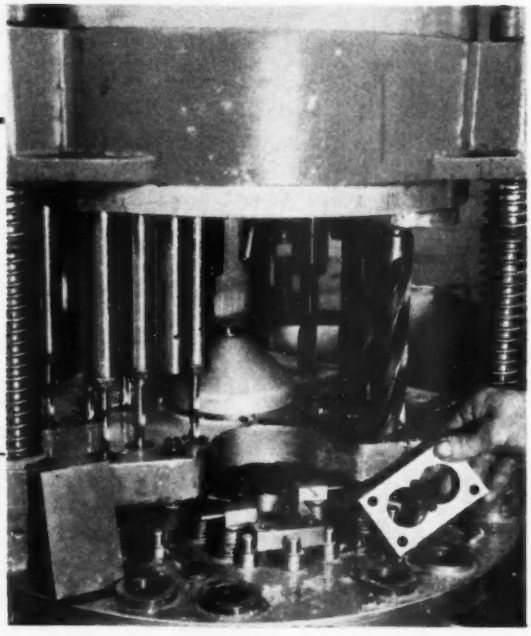

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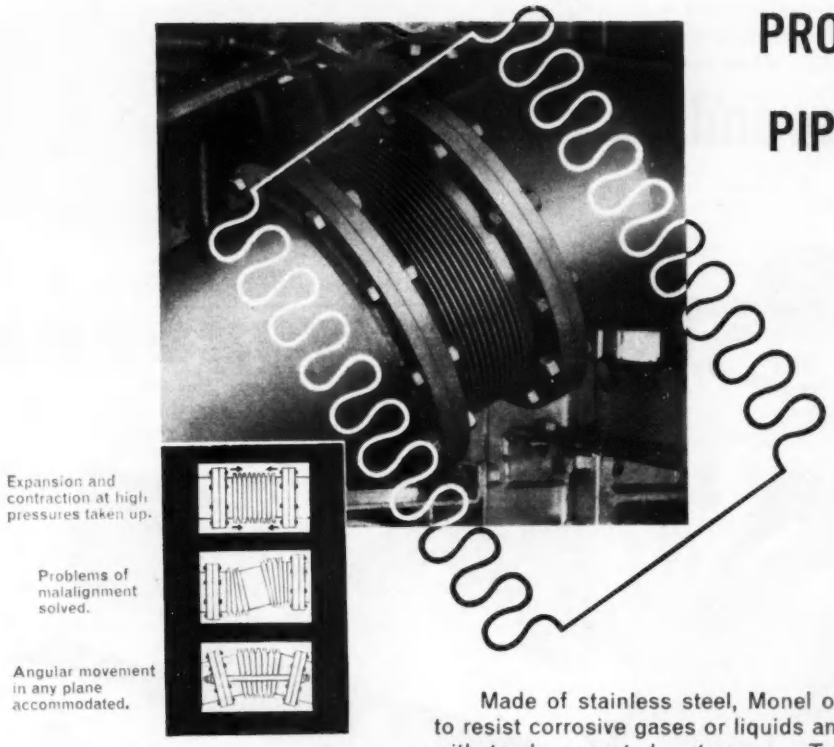

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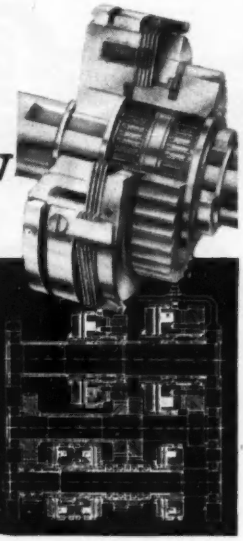

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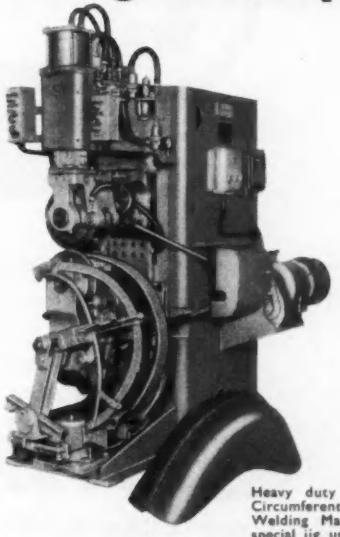

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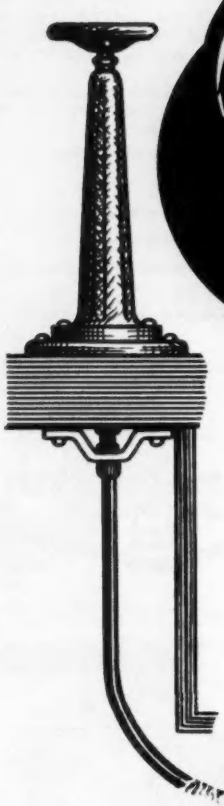

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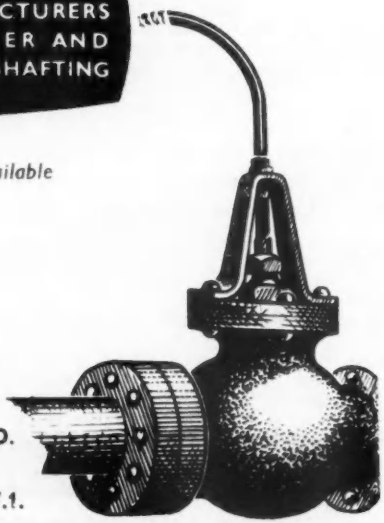

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Stainless Steel Float, in clear glass tube.

Customers when ordering should state—
(*a*) Specific Gravity and Working Pressure.
(*b*) Maximum and Minimum Rates of Flow.

Size B.S.P. ins.	Max. Capacity Cu. ft./Hr. Coal Gas @ 5/10" P.D.
¼	25
⅜	60
½	110
¾	230
1	420
1¼	650
1½	900
2	1600
2½	2500

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WHITEFIELD Manchester

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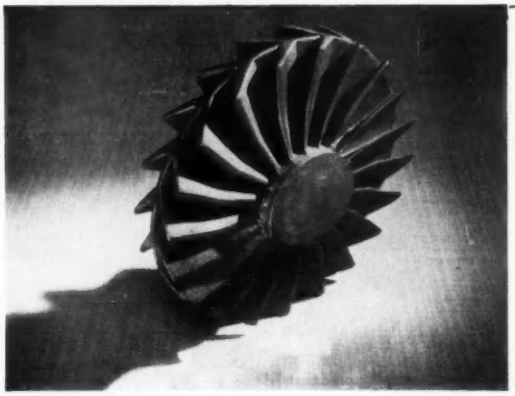
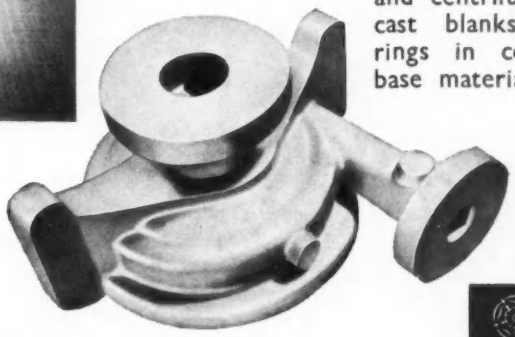


Pump impeller, sand cast in Superston bronze.

Two examples from our range of castings

We specialize in the production of sand, die and precision castings in Aluminium, Magnesium and Bronze alloys; also, forgings and centrifugally-cast blanks and rings in copper base materials.



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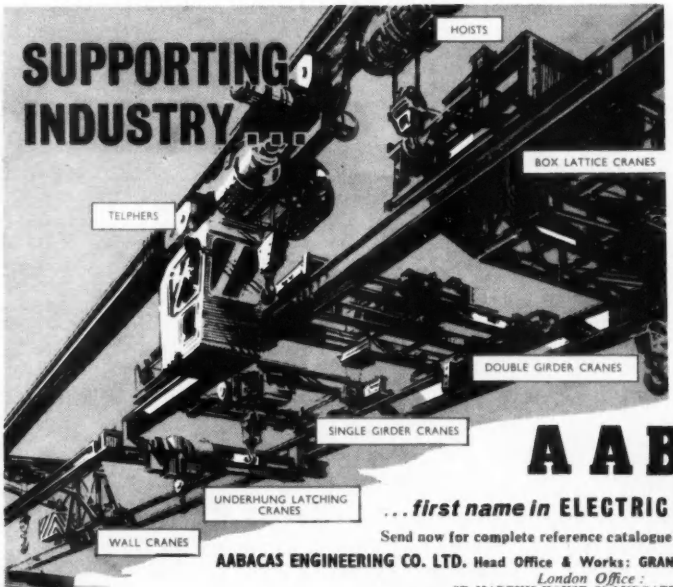

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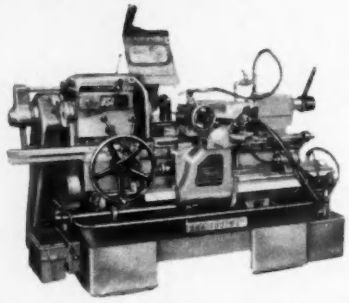
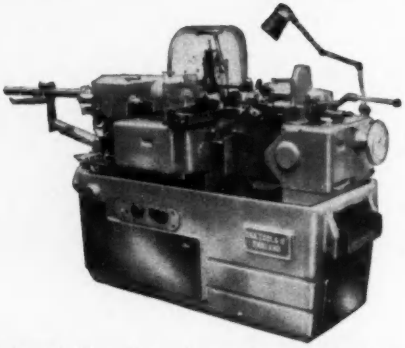
A1

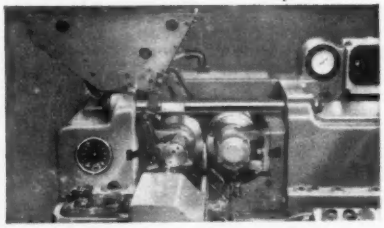
B·S·A production machines



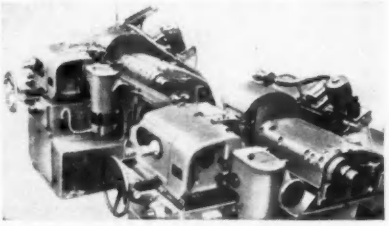
B.S.A. C.L.1. copy turning lathe. For small batch or quantity repetition copy turning multi-diameter shafts, spindles and similar forms. The tracer arm is linked through the hydraulic system to a slide carrying a single-point turning tool. An attachment for copying from a flat template can be supplied as can a rear slide for facing and grooving. Swing over tool slide 8". Distance between spindle flange and tailstock centre 28". Longitudinal travel of tool 26". Transverse stroke of hydraulic slide 2⅞". Diameter of Master 5¼" max. Spindle speeds 217 to 1,810 r.p.m. Feed range 0.003" to 0.030".



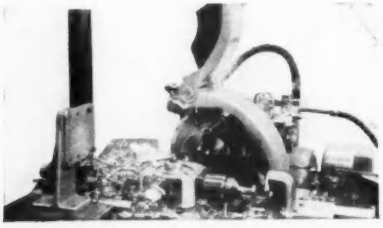
B.S.A. single-spindle automatic screw machines are made in several types including ½", ¾", 1", 1¼", 1⅝" and 2" diameter capacity. Turrets have six stations, but eight station turrets can be fitted to the larger machines. All sizes are arranged for double indexing of turret. A wide range of attachments includes screw-slotting, nut tapping, rear end drilling, cross drilling, spindle brakes and devices for automatic loading for second operation work.



B.S.A. form generator equipped for rolling threads ⅜" dia. on both ends of rod-type component. Two pieces rolled per revolution of the dies, output 90 components per minute. Components are fed from a hopper with an internal adjustable locating plate which permits feeding of parts varying from 4⅜" to 6" long and holds 1,000 workpieces.



Two B.S.A. No. 8 centreless grinding machines linked for transfer of component for two operations. A chute type magazine gravity-loads workpieces to an endless chain conveyor. On completion of grinding on the first machine the components are passed by intermediate conveyor to the workplate between the wheels of the second machine for another grinding operation.



Cup type components delivered from a magazine are received by revolving collets on the turret faces and presented to the chuck for machining from the cross slides on this **B.S.A. 5M fully automatic chucking machine.** Turret index brings a finished component to the station where it is stripped from the collet pneumatically while the succeeding component is being machined. Cycle times: 9 to 15 seconds (depending on the size of the component for which the set-up is adjustable).

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